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A Quick Look

at this issue

☐ **Coordination of geology and geophysics pays off . . .** Here are the more important recent improvements in geological and geophysical methods and tools, and how different approaches are being combined to offset limitations of each. Technicians are not only finding better ways to explore for oil individually but also how to work together more effectively. . . . . Page 87

☐ **How to make geochemical exploration succeed . . .** Geochemical approaches, when coordinated with geology and geophysics, yield good results. Like other oil search tools, geochemistry is of limited use by itself. New concepts, and a synopsis of previous geochemical research are combined here. . . . . Page 93

☐ **Why sedimentary structures show high self-potentials . . .** Years of surface and telluric electrical survey work indicate that domal sedimentary structures show high self-potentials, measured horizontally at the surface. Isopotential contours on closed structures provide pictures similar to subsurface structural contours. Earth currents, operating by electrolysis, produce observable anomalies. . . . . Page 97

☐ **Gravity-photogeology method boosts accuracy, cuts costs . . .** Coordination of photogeology and gravity methods improves efficiency of both. Most oil fields show some surface expression detectable on aerial photos, even in extremely low-relief topography. Such photo anomalies can be verified with gravity surveys . . . . . Page 99

☐ **Palynology has important role in oil exploration . . .** Palynology is one of the most significant exploration tools developed during the past decade. Classification and correlation of ultramicroscopic fossils determines locations of ancient shorelines and other stratigraphic traps, more favorable areas and facies for oil and gas accumulation. . . . . Page 101

☐ **Electronic computers aid in many exploration phases . . .** Geologists and geophysicists can improve their work output through use of electronic data-processing equipment. Computers and other electronic data-processing gear are useful for geologic and seismic

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mapping, electrical and nuclear well log interpretation, and other functions. . . . . **Page 105**

☐ **Magnetic orientation of cores aids oil search . . .** Configuration of sandstone lenses and regional sand bodies can be indicated by a minimum number of wells from which sandstone cores are analyzed as to magnetic orientation. Work on outcrops of different geologic ages has shown positions of magnetic north through post-Paleozoic times, providing meaning to magnetic core orientations. . . . . **Page 112**

☐ **How to do refraction work by remote control . . .** A remote control refraction system to scan large, remote areas quickly with a minimum number of men utilizing readily portable equipment has been used in the field. A special application of this system is found in offshore operations. . . . . **Page 114**

☐ **How high are Free World oil search, development costs? . . .** Have you ever wondered just *how much money* is spent in the worldwide oil search? The Chase Manhattan Bank has provided some interesting answers, following completion of a recent study on over-all oil industry expenditures in the Free World. . . **Page 117**

☐ **Liquid hydrocarbon and natural gas reserves at record high . . .** Proved recoverable crude oil and natural gas liquids reserves totaled 38.2 billion barrels last December 31, up 1.5 billion barrels over 1958—a 13.3 year supply at December 31 production rates. These are just a few of the timely, informative statistics included in the latest annual American Petroleum Institute-American Gas Association report on U.S. reserves starting on. . . . . **Page 119**

☐ **Mexico is expanding its oil industry.** All phases of petroleum development in Mexico are being vigorously expanded. The expansion is necessary in order to keep the industry abreast of the country's sharply increasing demand for oil and gas. . . . . **Page 122**

☐ **Three-phase separators . . .** This final section of the Production Practices Manual discusses the three basic control methods for three-phase units and includes charts for determining liquid capacity of three-phase horizontal, vertical and spherical vessels. . **Page 127**

☐ **A new record—10,487 feet of 13⅜-inch casing . . .** Union Oil and Gas Corporation recently ran this record length of casing in its Ursule A. Simon well south of Crowley, La. For a complete discussion of this operation, turn to. . . . . **Page 134**

Because of enthusiastic reader response, all 10 Parts of WORLD OIL's Production Practices Manual on Producing Equipment for Natural Gas Wells soon will be available under a single cover at $1 per copy. Place your order now. Address: Reprint Department, WORLD OIL, P. O. Box 2608, Houston, Texas. Discount prices for quantity orders available upon request.

☐ **An artificial lift study can save you money . . .** A thorough study of the various types of lift conducted prior to installing pumping or gas lift equipment in the first well on a lease may save an operator thousands of dollars during the life of the lease. This article presents a procedure for evaluating the various types of artificial lift—rod pumping, hydraulic pumping and gas lift . . . . . **Page 137**

☐ **A geological evaluation of aerated water-drilled wells . . .** Aerated water drilling is a relatively new adaptation of the rotary method. Gulf Oil Corporation, having used both fresh water and sea water in a number of widely separated areas, has enough experience with this drilling approach to discuss its merits thoroughly . . . . . **Page 141**

☐ **Evaluation of Marshall's formula for permeability . . .** When experimentally measured permeabilities were compared with calculated values determined by Marshall's formulas it was found that the calculated absolute permeabilities were too low by a constant factor and relative permeabilities too high. However, ideas advanced by Marshall were used in deriving modified formulas which produce results that agree more closely with measured permeability values. . . . . **Page 150**

☐ **How to stabilize long exposed shale sections . . .** As well depths increase, the stabilization of the longer section of exposed formation imposes a severe load on the drilling fluid. Extensive laboratory evaluation of the shale controlling fluids have been undertaken between the mud, mud filtrate and formation solids. This article discusses these various parameters and how different mud systems are used to combat long exposed shale sections . . . . . **Page 154**

☐ **Search for oil is planned in Jamaica . . .** The British island of Jamaica in the West Indies is due to be explored and tested by drilling within the next 18 months by Jamaica Time Petroleum, Inc., of Wichita, Kan. Recent geological work has revealed encouraging geologic sections . . . . . **Page 174**

☐ **How to reduce downhole corrosion with inhibitors . . .** Although a number of corrective measures are available, properly applied inhibitors have been found effective in reducing corrosion problems. This article describes downhole corrosion problems and presents 21 methods for applying inhibitors. . . . . **Page 184**

Coming in June . . . Southeastern U. S. Issue

Oil Industry In Brief

Here are the latest industry trends, revealed by WORLD OIL research:

Demand Down. During first two months of 1960, total demand was down 2.5 percent from same 1958 period, and domestic demand was off 2.3 percent . . . See Page 25.

Inventories Up. Distillate stocks totaled 105 million barrels at February's end, up 25 percent over year ago totals. . . . See Page 25.

Gas liquids production up. U.S. production of natural gas liquids averaged 922,000 barrels daily in January-February, for a 5 percent increase over same month in 1959 . . . See Page 25.

Imports down. Total imports were down 11.9 percent during January-February, averaging 1,955,000 barrels daily, compared with 2,218,000 last year. . . See Page 25.

Well completions down. Average of 121 wells per day were completed during January-February, down 11 percent from 136-wells-per-day average during same 1959 period . . . See Page 29.

Rig totals down. The 3,582 drilling rigs operating at February's end reflected a 337-rig drop from the total operating on January 31, and 273 rigs less than were operating on the same date in 1959 . . . See Page 29.

Footage down. Operators drilled an average of 482,759 feet of hole per day during February, down 62,241 feet per day or 11.5 percent from January average . . . See Page 29.

Wildcatting holds steady. Operators drilled average of slightly less than 26 wells per day during January-February, compared with slightly more than 26 wells per day during same 1959 period . . . See Page 29.

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WORLD OIL (formerly The Oil Weekly) and The COMPOSITE CATALOG for the drilling-producing industry.
PIPE LINE INDUSTRY and The PIPE LINE CATALOG for the oil and gas pipe line industry.
PETROLEUM REFINER and The REFINERY CATALOG for the oil, gas and petrochemical processing industry.

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"We have Ford Trucks with 101,090 to 146,436 off-road miles and no major repairs"

says Mr. M. C. Kelsey
President
Rayflex Exploration Co.
Dallas, Texas

"Doing seismic work for the petroleum companies in their search for new oil fields takes our crews far from any road. Our trucks must follow a line cross-country, regardless of the terrain. And Ford Trucks come through where the others won't.

"We have 46 Ford Trucks from pickups to heavies. The Ford Pickups are used as survey trucks and personnel carriers . . . two-tonners are shooting trucks, recording units and drilling trucks . . . the Ford F-800 Heavies carry an HD 1000 combination air-and-water drill.

The Rayflex Exploration Co. of Dallas serves the petroleum industry throughout the United States from Canada to the Gulf, and operates overseas as well. At the present time it has seven crews in the field.

The trucks shown *(above)* are two of the company's Ford F-600's equipped with HD V-8 engine, 4-speed transmission, 2-speed rear axle, special grille guard, winch and non-spin rear axle.

Looking Ahead

What's new in exploration . . . New vibratory method of exploring the subsurface has been revealed by Continental Oil Company. Impulses created by vibrators are reflected by subsurface horizons and record in similar fashion to seismograph impulses. Method is particularly effective in areas where explosives are forbidden, or where shot hole drilling is not practical.

Helicopter adaptation of "thumping" method is in the works. Velocity studies are being made to develop unique version of weight-dropping exploration technique. Heavy (500 pound) concrete weights have been dropped from helicopters, reportedly from as high as 1,000 feet, in Canada hinterlands. Objective is to provide enough energy from single weight drop to give adequate signal-to-noise ratio.

Accurate subsurface stratigraphic data from seismic interpretation is on the way. In West Germany, drilling has borne out seismic correlations of Bentheimer sandstone across a fault and to the feather-edge. Use of broad band filters, tapered shot patterns, and greater than normal number of jugs made this interpretation possible.

Airborne gravity meter is being developed, aided by recently-perfected automatic Doppler navigation technique.

Looking ahead in Washington . . . American Petroleum Institute President Frank M. Porter says proposed Fuels Policy Study not only is totally unnecessary, it would merely duplicate other studies already underway. He adds: "It is API's belief that this nation's policy of competition is simultaneously a national fuels policy." . . . **Oklahoma Representative Jarman** has called for all presidential candidates to make a clear-cut statement of position on major issues affecting the oil and gas industry . . . **Move to hike minimum wages to $1.25 an hour** is now being heard by Landrum subcommittee, with several oil company representatives on hand to express their views . . . **Look for complete agreement of all natural gas producer groups** on new substitute natural gas bill in near future . . . **BuMines has suggested cut back in crude runs to stills during April** so inventories can return to more logical levels.

U.S. reserves at all-time high . . . Latest API-AGA reserve report reveals U.S. liquid hydrocarbon reserves totaled 38.2 billion barrels last December 31, up 1.5 billion barrels over same 1958 date. However, ratio of reserves to annual production decreased slightly, from 13.5 years' supply to 13.3 years. Natural gas reserves were up 3.3 percent to 262.6 trillion cubic feet. (**See Pages 119-121.**)

What it costs to produce helium . . . BuMines has opened Washington files on its helium operations, so private operators can determine cost of processing helium-bearing natural gases. Bureau's new plant at Keyes, Oklahoma produces helium at a cost of $8.57 per Mcf—17-year-old plant at Exell, Texas produces 240 MMcf annually at $9.88 per Mcf.

BuMines currently is selling helium to other government agencies for about $16.00 per Mcf, and to non-government purchasers for $19 per Mcf.

Now you can see down-hole casing damage . . . Stereo photography, long used for inspection of casing damage and corrosion in water wells, now is being adapted to down-hole inspection of oil wells. An electrically operated camera, carrying its own light source, is lowered into well on electrical cable. Special techniques are used when camera is operated inside an oil column.

More than 100 stereo frames can be made on single run. Corrosion damage, collapsed pipe or position of fish, are much more easily examined and repaired. And you can have your choice of seeing the bad news in color or black and white.

Good Wells Make Good News

A Report on Recent Engineered Acid Treatments

April 1, 1960

Dowell engineers can now use more proved services, products and techniques than ever before to design effective acid treatments. Here are four recent treatments that used advanced engineering to good effect.

- **Spencer County, Indiana** (New Oil Well) This well made a show of oil upon completion into the Rosiclare. The pay is a dirty lime. Dowell recommended acidizing with 3000 gallons inhibited acid. Two Dowell addition agents were used to prevent emulsions and control silicate swelling. Injection rate was held to 1.5 bpm during treatment. 30 days after treatment well tested 95 bopd with no water — an unusually good well for the area.

- **Central Alberta, Canada** (New Oil Well) This well was completed in the Slave Point formation on the edge of a pool in the Swan Hills region. The pay is a fast-reacting limestone. There was no production and the operator considered abandonment. Dowell engineered a treatment using the "Acid Guide"*. The formation was washed 4 hours with 500 gallons Mud Acid. Then 500 gallons Retarded Acid was squeezed into the formation at one bpm and 3800 psi. After treatment, the well made field allowable and was put on production.

- **Eastland County, North Texas** (New Oil Well) This well went to water after conventional perforating and acidizing. The operator squeezed with Cealment*, latex-cementing service; then used Abrasijet*, abrasive-fluid jetting service, to re-perforate into the Marble Falls conglomerate from 2955 to 2968 feet. Next, 250 gallons Dowell acid were jetted into the formation through the tool used in Abrasijet. Before treatment, well produced 100 per cent water. After treatment, it produced 25 bopd with no water.

- **Lea County, New Mexico** (Old Oil Well) This well had depleted the McKee sand and was plugged back and re-completed in the Abo limestone from 7122 to 7226 feet. Core analysis showed iron compounds to be present. Dowell recommended Stabilized Acid to prevent the possible precipitation of gummy iron hydroxides. 6000 gallons Stabilized Acid were injected. Perforation ball sealers were used during treatment. Production increased from a show to 200 bopd (with no water) through a 20/64th-inch choke.

Engineered acidizing by Dowell helps you improve profits by getting maximum return from your acidizing dollar. For service or detailed information, contact the Dowell office or station nearest you. Dowell services and products are offered from more than 150 locations in the United States, Canada, Venezuela, and Argentina. Dowell, Tulsa 1, Oklahoma.

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Exploration – a weapon for peace

By Ben H. Parker, President-elect, AAPG
Frontier Refining Company, Denver

GEOLOGY—the firm foundation for sound petroleum exploration—has been so effective in pointing the way to adequate reserves that some people have questioned whether the petroleum industry may not be in jeopardy because of the magnitude of world crude reserves and productive capacity. In this period of rapidly varying degrees of cold war, the political effect of these expanding reserves as well as the adequacy of available petroleum for possible military needs must be given consideration in any appraisal of exploration requirements and programs.

Since the first application of the anticlinal theory to the scientific search for oil and gas more than 75 years ago, geology has been utilized so successfully in oil-finding that many facets of civilization—especially transportation—have been revolutionized by use of the abundance of oil which has been discovered. Until two or three decades ago, reserves and productive capacity were largely centered in a small number of geographic areas and were in great measure controlled by a few nations.

Such concentration of oil, both geographic and proprietary, gave rise at times during the past few decades to the development of national pressures for shifts in political controls of reserves and production. In fact, these demands were important factors among the complex causes of the two world wars and at other times have been extended to limits seriously endangering world peace.

In view of present anxieties concerning world peace and these nationalistic demands for access to petroleum reserves, a question naturally arises concerning the effect that aggressive exploration may have had and may still have on national security and world tensions.

Many nations have reserves. The enormous wartime demands for petroleum have been met as they have developed, but the highly successful results of geologically-directed exploration are no less outstanding as a force for peace than as an essential requirement for modern warfare. Where, only three decades ago, less than 20 countries were capable of producing more than a million barrels of crude petroleum annually, now more than 40 nations sustain annual production in excess of that amount. During the same period, as a result of scientifically-directed exploration, world production has increased almost fivefold from less than a billion and a half barrels annually to about 7 billion barrels.

The true importance of this great increase in productive capacity, which at times seems to threaten the economic stability of our industry, lies not in the magnitude of the expansion but in its effect on large segments of the world's population and the resulting changes in national control and geographic distribution of reserves and production. No longer is it necessary for many of the peoples and nations, petroleum "have nots" only one or two decades ago, to depend entirely on foreign sources for petroleum. No longer can one world power aspire to acquire the petroleum productive capacity of a few important producing regions (or even of one hemisphere) and thereby be in a position to control effectively the liquid fuel supplies essential to the needs of its potential enemies.

With the vastly broader geographic distribution of crude reserves and production which have been discovered and developed within the past thirty years there is much less strategic importance attached to the petroleum deposits of any one nation. Consequently, there has been a reduction in pressures for realignment of political dominion of these reserves.

The geologist and other exploration personnel following him have, with their success in oil-finding, assured the ample reserves which may already have dampened and tempered the recent demands for changes in jurisdictional control of reserves which have and could endanger world peace. In reality, the profession of petroleum geology through its success in the direction of the search for petroleum deposits may have provided one effective deterrent to war and may indeed have made exploration an effective weapon for peace.

About the Author

Ben H. Parker is president-elect of The American Association of Petroleum Geologists. His installation as president will take place at Atlantic City, N. J., during the joint AAPG-SEPM annual meeting, April 25 through 28. Parker is vice president and director of The Frontier Refining Company, Denver. A native of Oklahoma City, he holds E.M. and D.Sc. degrees from the Colorado School of Mines and an LL.D degree from Colorado College. His oil industry career includes geological posts with Marland Oil Company, Gypsy Oil Company, Gulf Oil Corporation, and Yacimientos Petroliferos Fiscales (Argentina), before he became vice president of Frontier in 1942 and director in 1951. He has also been associated with the geology faculty of the Colorado School of Mines, and has served in various civic and state governmental posts related to geology and engineering. Parker is a fellow of GSA, and a member of AIME, API, the Mining and Metallurgical Society of America, and the Rocky Mountain Association of Geologists.

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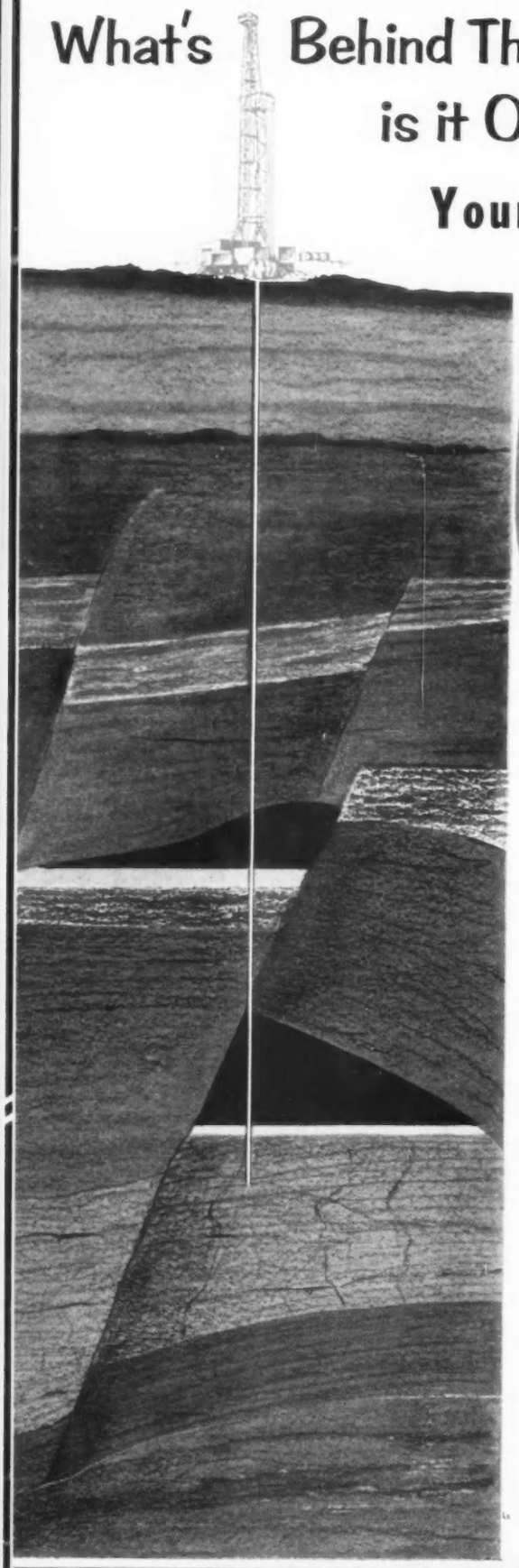
Your Answer...



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Lagging demand weakens markets

DISAPPOINTING DEMAND for petroleum products in 1960 can largely explain the persistence of weak markets, low prices, and unsatisfactory financial results in the industry.

In the first two months of 1960 total demand for petroleum was 2.5 percent lower than in the like months of 1959. Domestic demand was off 2.3 percent and exports showed further contraction.

Lower demand in 1960 has reflected primarily the relatively light consumption of distillate fuel oils, kerosine, and residual fuel oil, due to milder than normal winter weather. Daily average demand for distillate fuel in January and February 1960 was 8.3 percent smaller than in those months of 1959. Kerosine demand was down 15.5 percent. Residual fuel oil demand was off 9 percent.

Helping to depress residual consumption was the fact that because of relatively mild weather, many industrial consumers were able to go on using natural gas instead of having to switch temporarily to oil during the winter, to release more gas for residential and commercial use. Ordinarily, residual must substitute importantly for natural gas at industrial plants in winter.

Gasoline demand has held up relatively better than demand for other products, but even it has been disappointing. Daily average demand for gasoline in January-February 1960 was 1 percent less than in those months a year ago.

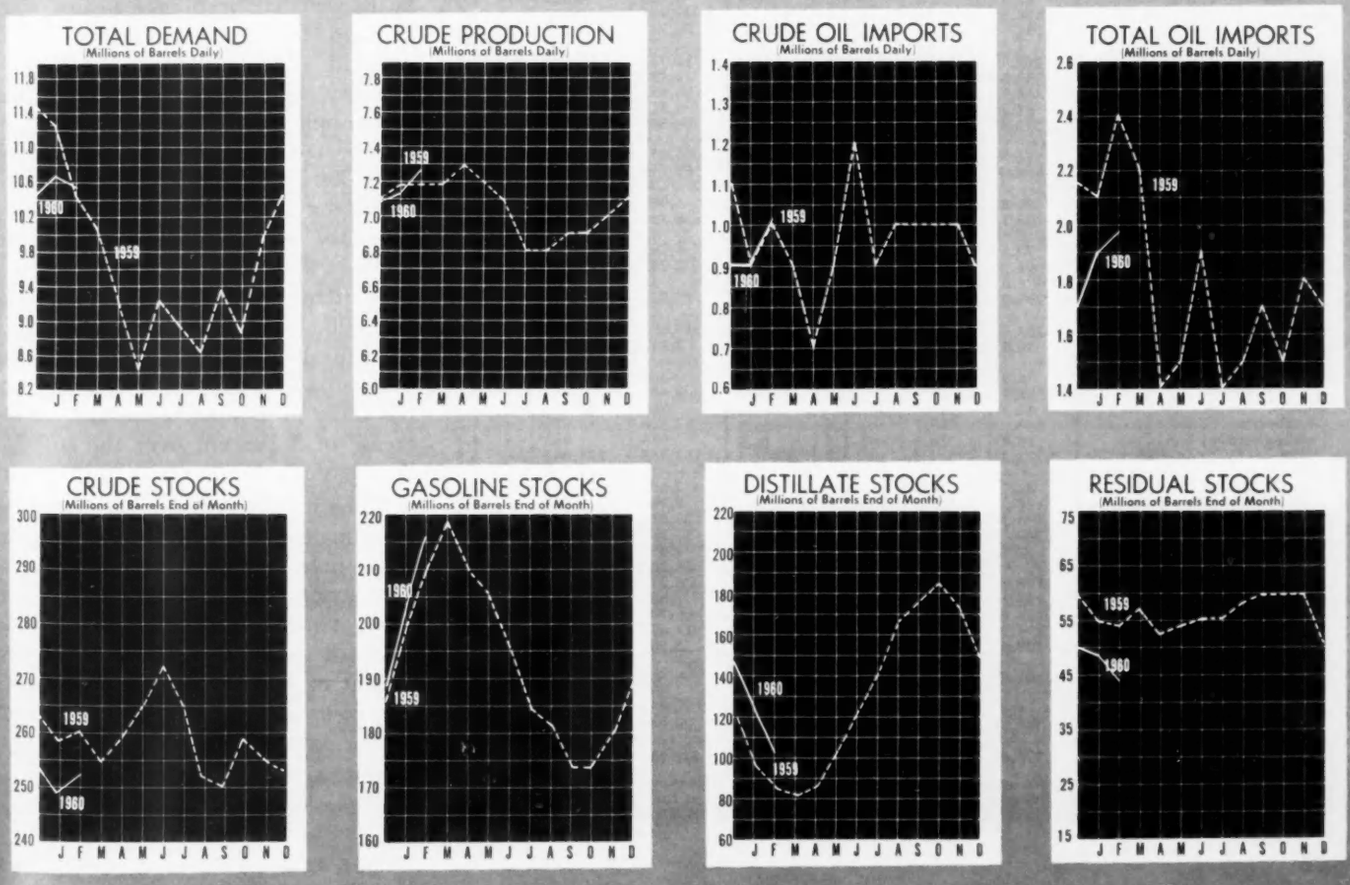
Supply. While demand for petroleum has been disappointing this year, the industry has been taking notice of lagging sales, particularly during the past month, and has been trying to adjust supply into better balance with the demand. The results have been fairly satisfactory, in that stocks of crude oil and gasoline remain reasonable and refinery runs of crude oil have been curtailed.

However, stocks of distillate fuel oil became seriously excessive as sales lagged during relatively mild weather of December and January. And the surpluses of distillate have remained in February and March. Distillate stocks of 105 million barrels at the end of February were 25 percent greater than those of 84 million a year earlier.

Under the burden of the surplus, the markets for distillate have been weak, and wholesale prices were further reduced in early March.

To some extent it will be practical

Petroleum Trends...



U. S. Petroleum Demand and Supply (Thousand Barrels Daily)

ITEM	FEBRUARY 1960	FEBRUARY 1959	% Diff.	Jan. 1960	JANUARY-FEBRUARY 1960	JANUARY-FEBRUARY 1959	% Diff.
DEMAND							
All Oils, Total Demand	10,595	10,539	+ 0.5	10,738	10,669	10,945	— 2.5
Domestic Demand	10,370	10,306	+ 0.6	10,518	10,446	10,693	— 2.3
Export Demand	225	233	— 3.4	220	222	252	11.9
Gasoline, Total Demand	3,666	3,623	+ 1.2	3,640	3,653	3,690	1.0
Distillate, Total Demand	2,535	2,677	— 5.3	2,789	2,666	2,906	8.3
Kerosine, Total Demand	441	469	— 6.0	453	447	529	15.5
Residual, Total Demand	1,940	2,135	— 9.1	1,943	1,942	2,135	— 9.0
Other Oils, Total Demand	2,013	1,635	+12.3	1,913	1,961	1,685	+16.4
CHANGE IN STOCKS							
All Oils, Change in Stocks	—410	—94		—732	—576	—640	
NEW SUPPLY							
Total New Supply	10,185	10,445	— 2.5	10,006	10,092	10,305	— 2.1
Domestic Production, Total	8,215	8,090	+ 1.5	8,065	8,137	8,088	+ 0.6
Crude Oil	7,275	7,194	+ 1.1	7,160	7,216	7,210	+ 0.1
Natural Gas Liquids	940	896	+ 4.9	905	922	878	+ 5.0
Imports, Total	1,970	2,355	—16.4	1,941	1,955	2,218	—11.9
Refined Products	956	1,303	—26.6	1,026	922	1,233	—19.6
Crude Oil, Total	1,014	1,052	— 3.6	916	963	985	— 2.2
Crude, East Coast	759	801	— 5.2	689	723	785	— 7.9
CRUDE RUNS							
Crude Runs to Stills	8,081	8,127	— 0.6	8,262	8,174	8,181	— 0.1
Domestic Crude	7,134	7,183	— 0.7	7,359	7,250	7,219	+ 0.4
Foreign Crude	947	945	+ 0.2	903	924	962	— 4.0

U. S. Stocks of Oils (Million Barrels at End of Month)

KIND OF OIL	TOTAL IN U.S. Feb. 1960	Feb. 1959	% Diff.	Jan. 1960	EAST OF CALIFORNIA Feb. 1960	Feb. 1959	% Diff.	Jan. 1960
All Oils	769.0	751.8	+ 2.3	780.9				
Crude Oil	253.0	260.0	— 2.7	248.9	219.4	219.0	+ 0.2	216.6
Gasoline	217.5	210.4	+ 3.4	204.6	186.9	181.5	+ 3.0	175.1
Distillate Fuel Oil	104.7	84.1	+24.5	124.4	93.6	72.6	+28.9	112.7
Kerosine	21.1	19.7	+ 7.1	24.7	20.8	19.3	+ 7.8	24.3
Residual Fuel	44.9	54.2	—17.2	47.8	28.9	25.5	+13.3	29.7
Other Oils	127.8	123.4	+ 3.6	130.5				

U.S. Crude Oil Production, by States (Thous. Bbls.)

STATE or DISTRICT	Daily Average for Month Feb. 1960	Feb. 1959	% Diff.	Jan. 1960	Total, January-February 1960	1959	% Diff.
Alabama	19.2	9.5	+102.1	17.0	1,085	738	+ 47.0
Arkansas	82.0	75.6	+ 8.5	70.0	4,550	4,626	— 1.6
California	828.4	839.2	— 1.3	835.2	49,915	49,684	+ 0.5
Colorado	129.7	128.0	+ 1.3	128.4	7,742	7,470	+ 3.6
Florida	1.2	1.0	+ 20.0	1.2	72	68	+ 5.9
Illinois	212.9	219.3	— 2.9	218.0	12,933	13,047	— 0.9
Indiana	33.8	31.3	+ 8.0	32.0	1,973	1,917	+ 2.9
Kansas	310.5	329.4	— 5.7	311.9	18,673	19,638	— 4.9
Kentucky	63.1	64.1	— 1.6	64.0	3,812	3,774	+ 1.0
Louisiana	1,082.8	949.4	+ 14.1	1,069.6	64,559	55,807	+ 15.7
North Louisiana	114.8	125.0	— 8.2	113.3	6,843	7,306	— 6.3
South Louisiana	968.0	824.4	+ 17.4	956.3	57,716	48,501	+ 19.0
Michigan	30.0	25.5	+ 17.6	33.3	1,900	1,494	+ 27.2
Mississippi	145.1	118.9	+ 22.0	146.7	8,754	7,063	+ 23.9
Mo.-So. Dak.-Tenn.	0.8		+100.0	0.6	42	4	+950.0
Montana	79.3	83.0	— 4.5	80.2	4,785	4,783	+ 0.1
Nebraska	63.2	56.9	+ 11.1	62.9	3,783	3,427	+ 10.3
Nev.-Wash.-Alaska-Ariz.	1.0	0.6	+ 66.6	0.8	53	53	
New Mexico	299.9	279.3	+ 7.4	301.0	18,026	16,308	+ 10.5
Southeast	263.9	241.5	+ 9.3	259.1	15,683	14,505	+ 8.1
Northwest	36.0	37.8	— 4.8	41.9	2,343	1,803	+ 29.9
New York	4.9	5.1	— 3.9	5.1	300	331	— 9.4
North Dakota	58.9	49.4	+ 19.2	58.0	3,505	2,858	+ 22.6
Ohio	12.2	15.5	— 21.3	13.0	757	871	— 13.1
Oklahoma	560.6	568.7	— 1.4	556.9	33,520	33,078	+ 1.3
Pennsylvania	16.0	16.3	— 1.9	16.5	975	935	+ 4.3
Texas	2,778.4	2,884.4	— 3.7	2,673.5	163,455	171,064	— 4.5
Dist. 1: South Central	44.5	44.7	— 0.5	43.0	2,625	2,635	— 0.4
Dist. 2: Middle Gulf	127.5	129.7	— 1.7	121.5	7,463	7,600	— 1.8
Dist. 3: Upper Gulf	390.2	420.4	— 7.2	378.2	23,042	24,741	— 6.9
Dist. 4: Lower Gulf	202.7	207.5	— 2.3	189.6	11,757	12,161	— 3.3
Dist. 5: East Central	27.7	32.3	— 14.2	27.4	1,652	1,873	— 11.8
Dist. 6: Northeast	273.9	293.3	— 6.6	263.3	16,103	17,219	— 6.5
Dist. 7-B: North Central	138.9	144.2	— 3.7	135.5	8,228	8,454	— 2.7
Dist. 7-C: West Central	133.1	143.3	— 7.1	127.1	7,800	8,471	— 7.9
Dist. 8: West	1,136.2	1,147.4	— 1.0	1,083.6	66,544	67,117	— 0.9
Dist. 9: North	194.2	209.7	— 7.4	195.0	11,679	12,428	— 6.0
Dist. 10: Panhandle	109.4	108.0	+ 1.3	109.3	6,562	6,282	+ 4.5
Utah	107.4	108.3	— 0.8	109.3	6,503	6,372	+ 2.0
Virginia						1	—100.0
West Virginia	5.4	5.9	— 8.5	5.7	336	336	
Wyoming	348.7	329.5	+ 5.8	349.5	20,949	19,614	+ 6.8
Total, U.S.	7,275.4	7,194.1	+ 1.1	7,160.3	432,957	425,361	+ 1.8

Sources for above 3 tables: Bureau of Mines monthly reports, except last two months based on API and B. of M. weekly reports and WORLD OIL estimates, and all Texas districts from API.

in coming months for refiners to convert distillate fuel oil into gasoline and thus market it in that form. But much of the distillate will have left the refinery and entered storage from which it cannot be economically retrieved and re-run at the plants. Surplus distillate therefore may remain a problem until next fall.

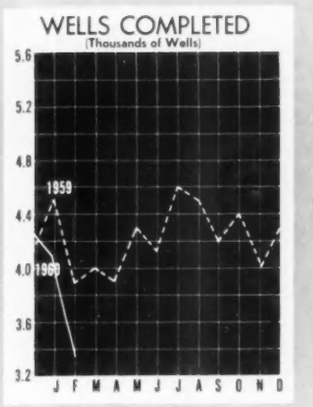
Gasoline stocks are not seriously excessive but they are quite ample, and there is need for active precaution against surpluses. They totaled 217.5 million barrels at the end of February, and were 3.4 percent above the level of 210.4 million barrels held one year previously. This increase was not justified by gasoline demand, which was not up but down 1 percent from last year during the first two months of 1960.

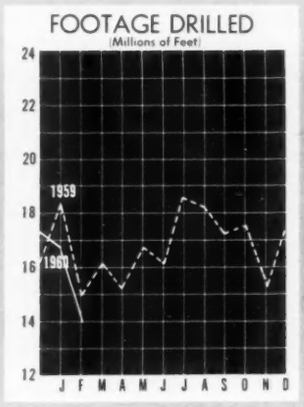
At this time, with gasoline demand due to begin increasing seasonally, the markets for gasoline are generally firm, and there has been some marking up of wholesale prices. Reductions of refinery runs by numerous refiners in recent weeks have held new supplies of gasoline within reasonable bounds, helping to stabilize the markets. It remains to be seen, however, if gasoline surpluses will be avoided and if satisfactory prices can be maintained.

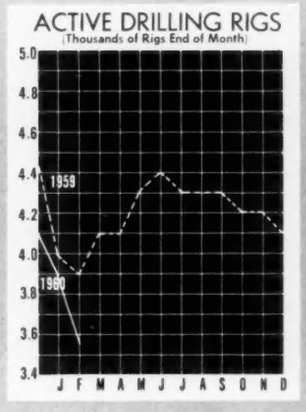
The industry so far in 1960 has fairly well balanced new supply with demand for petroleum. While total demand was down 2.5 percent for January and February 1960, total new supply was held 2.1 percent under a year ago. Crude oil production of 7,216,000 barrels daily was only slightly above the 7,210,000 daily of January-February 1959. Total imports were down 11.9 percent in averaging 1,955,000 barrels daily, compared with 2,218,000 last year. U.S. production of natural gas liquids, however, is up substantially. It averaged 922,000 barrels daily in January-February, an increase of 5 percent over the 878,000 barrels daily of like months last year.

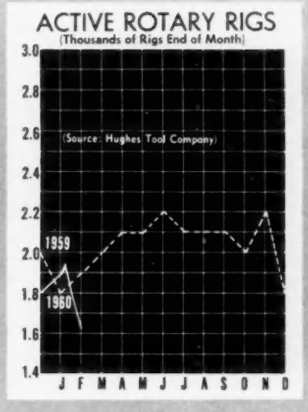
Some independent refiners are complaining that liquid products derived from natural gas are causing overproduction and weak markets. They assert that production at gasoline plants is not limited by proration, like output of refineries processing crude; and complain that much of the output of the gasoline plants is put through auxiliary units that further refine it into gasoline, kerosine, and distillate.

Drilling Activities.









Drilling activity continues to decline

CONTINUED TIGHT proration schedules and severe winter weather were major factors in another drop in U.S. drilling activity during February. An average of only 115 well completions per day were reported, down 9.4 percent from the 127 wells completed daily in January, and down 12.9 percent from the 132-well daily average in February 1959.

Daily completions during the first two months of 1960 averaged 121 wells, down 11 percent from the 136-well daily average during the same 1959 period. The 1960 daily average also was down 12 percent from the 138 wells completed daily in 1958, and 22 percent from the 155 wells per day completed during the first two months of 1957.

Also, the 3,582 drilling rigs operating at the end of February reflected a 337-rig drop from the 3,919 rigs operating on January 31, and 273 rigs less than were operating on the same date in 1959.

Wildcatting activity almost held its own during the first two months, averaging slightly under 26 wells per day, compared with slightly more than 26 wells per day during the same 1959 period.

Summary of U. S. Wildcat Drilling

ITEM	Feb. 1960	Jan. 1960	TWO MONTHS January-February 1960	1959	% Diff.
New Field Discoveries:					
Oil	31	64	95	120	—20.8
Distillate	6	8	14	16	—12.5
Gas	17	19	36	46	—21.7
Total Discoveries	**54**	**91**	**145**	**172**	**—15.7**
Dry Wildcats	**584**	**809**	**1,393**	**1,383**	**+ 0.7**
Total Wildcats	**638**	**900**	**1,538**	**1,555**	**— 1.1**
(Percent Productive)	8.5	10.1	9.4	11.1	.....
(Percent Dry)	91.5	89.9	90.6	88.9	.....

Summary of U. S. Drilling Activity

ITEM	Feb. 1960	Jan. 1960	TWO MONTHS January-February 1960	1959	% Diff.
New Wells Completed:					
Oil	1,636	1,852	3,488	4,148	—15.9
Distillate	61	86	147	145	+ 1.4
Gas	328	358	686	582	+17.9
Service	49	34	83	137	—39.4
Dry	1,247	1,611	2,858	3,007	— 5.0
Total Wells	**3,321**	**3,941**	**7,262**	**8,019**	**— 9.5**
Footage Drilled (Millions of Feet)	**14.0**	**16.9**	**30.8**	**33.5**	**— 8.1**

U.S. Drilling Activity in February and First Two Months, 1960-1959

STATE or DISTRICT	TOTAL NEW WELLS COMPLETED AND FOOTAGE DRILLED: DETAILS FOR FEBRUARY, 1960 — Oil	Dist.	Gas	Dry	Service Wells	TOTAL NEW WELLS — Feb. 1960	Jan. 1960	Feb. 1959	Total Footage February 1960	DETAILS FOR JANUARY-FEBRUARY — NEW WELLS — 1960	1959	Percent Diff	FOOTAGE — 1960	1959	WILDCAT DRILLING IN FEBRUARY AND FIRST TWO MONTHS, 1960-1959 — DETAILS FOR FEB., 1960 — Oil	Dist.	Gas	Dry	Total Wildcats	DETAILS FOR JANUARY-FEBRUARY — Oil	Dist.	Gas	Dry	TOTAL WILDCATS — 1960	1959	DRILLING RIGS IN OPERATION (Rigging up, Drilling, Temp. Shut-down) — Feb. 29 1960	Jan. 31 1960	Feb. 28 1959
Alabama	4	....	....	....	....	4	7	8	42,738	11	20	— 45.0	93,890	194,640	....	....	....	....	....	....	....	....	2	2	4	4	3	16
Alaska	....	....	....	....	....	....	1	....	....	1	1	....	11,200	12,046	....	....	....	....	....	....	....	....	1	1	1	5	5	5
Arizona	....	....	....	1	....	1	1	1	585	2	1	+ 50.0	7,180	2,000	....	....	....	1	1	....	....	....	2	2	1	4	2	1
Arkansas	24	....	2	25	....	51	50	65	169,521	101	147	— 31.3	342,077	473,539	....	....	....	11	11	....	....	....	21	21	18	25	34	50
California	65	....	4	22	4	95	122	123	374,859	217	245	— 11.4	951,108	1,158,419	....	....	....	15	15	2	....	2	42	46	46	102	95	124
Colorado	12	....	7	38	....	57	90	54	308,452	147	108	+ 36.1	799,297	590,314	2	....	1	24	27	6	....	2	66	74	61	56	80	57
Illinois	58	....	....	70	....	128	240	119	253,500	368	367	+ 0.3	731,540	824,350	....	....	....	41	41	3	....	....	121	124	84	253	274	213
Indiana	17	....	....	54	....	71	80	59	89,443	151	132	+ 14.4	198,595	223,854	....	....	....	32	32	....	....	....	63	63	31	125	136	80
Kansas	134	....	8	106	4	252	334	243	902,352	586	570	+ 2.8	2,117,465	2,049,022	4	....	....	53	57	17	....	2	131	150	167	227	246	331
Kentucky	134	....	22	76	6	238	235	238	208,063	473	449	+ 5.3	403,878	398,138	1	....	....	3	4	1	....	....	10	11	22	111	138	131
Louisiana	99	16	26	96	....	237	243	296	2,009,459	480	659	— 27.2	4,034,907	5,237,608	1	....	2	35	38	4	2	2	61	69	86	327	323	256
North Louisiana	23	....	14	26	....	63	70	119	244,073	133	230	— 42.2	490,855	871,487	....	....	1	9	10	....	....	1	18	19	28	52	59	42
South Louisiana	76	16	12	70	....	174	173	177	1,765,386	347	429	— 19.1	3,544,052	4,366,121	1	....	1	26	28	4	2	1	43	50	58	275	264	214
*Offshore	19	6	4	18	....	47	39	32	503,298	86	88	— 2.3	886,074	861,680	....	....	....	5	5	....	....	....	6	6	3	49	54	48
Michigan	30	....	1	33	....	64	59	46	230,454	123	85	+ 44.7	430,763	234,457	1	....	....	16	17	2	....	....	37	39	24	109	100	89
Mississippi	30	1	1	28	....	60	65	32	595,317	125	100	+ 25.0	1,149,564	930,157	2	....	....	21	23	3	....	....	45	48	36	78	85	68
Missouri	....	....	....	....	....	....	2	2	....	2	2	....	6,800	1,364	....	....	....	....	....	....	....	....	....	....	1	1	1	3
Montana	8	....	....	14	....	22	19	30	86,728	41	57	— 28.1	168,184	238,226	1	....	....	4	5	2	....	2	11	15	20	25	32	40
Nebraska	18	....	....	43	....	61	126	50	346,210	187	95	+ 96.8	1,105,408	533,142	2	....	....	25	27	5	....	....	73	78	42	36	33	43
New Mexico	71	....	38	33	....	142	179	137	654,982	321	253	+ 26.9	1,484,537	1,050,315	1	....	2	20	23	10	....	4	51	65	34	111	133	161
Southeast	62	....	3	25	....	90	110	63	425,195	200	131	+ 52.7	953,665	632,892	....	....	....	14	14	6	....	2	39	47	26	79	70	83
Northwest	9	....	35	8	....	52	69	74	229,787	121	122	— 0.8	530,872	* 417,423	1	....	2	6	9	4	....	2	12	18	8	32	63	81
New York	12	....	1	4	7	24	25	22	42,215	49	44	+ 11.4	85,715	74,380	....	....	....	....	....	....	....	....	....	....	....	25	25	25
North Dakota	17	....	....	7	1	25	27	36	151,490	52	72	— 27.8	319,316	450,542	....	....	....	2	2	....	....	....	8	8	17	17	37	45
Ohio	39	....	18	30	....	87	87	67	213,649	174	140	+ 24.3	419,032	376,590	1	....	....	3	4	2	....	....	6	8	3	178	188	202
Oklahoma	144	4	30	103	4	285	378	499	1,278,929	663	1,092	— 39.3	2,912,946	3,617,390	4	1	1	26	32	8	2	5	70	85	149	395	499	435
Pennsylvania	18	....	21	8	13	60	65	49	160,519	125	91	+ 37.4	353,437	295,077	....	....	1	....	1	....	....	1	2	3	3	180	195	183
South Dakota	2	....	....	3	....	5	5	3	43,220	10	3	+233.3	72,204	11,311	....	....	....	1	1	....	....	....	4	4	2	1	5	2
Tennessee	1	....	....	20	....	21	21	10	21,000	42	20	+110.0	42,000	20,000	....	....	....	10	10	....	....	....	20	20	4	25	25	25
Texas	639	39	88	379	7	1,152	1,322	1,356	5,118,398	2,474	2,963	— 16.5	11,261,333	13,222,779	11	4	8	209	232	29	9	14	474	526	622	834	862	962
Dist. 1: South Central	43	2	1	35	....	81	89	69	219,132	170	158	+ 7.6	488,044	428,480	....	....	....	25	25	....	....	....	50	50	48	32	37	28
Dist. 2: Middle Gulf	10	9	13	22	....	54	63	46	347,965	117	115	+ 1.7	770,181	722,556	....	2	2	13	17	....	3	2	29	34	40	51	51	43
Dist. 3: Upper Gulf	39	12	3	35	....	89	106	86	641,428	195	193	+ 1.0	1,417,755	1,416,216	1	1	....	20	22	2	3	....	44	49	48	89	89	66
*Gulf of Mexico	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	1	....	1
Dist. 4: Lower Gulf-S.W.	18	16	11	29	....	74	86	91	418,029	160	204	— 21.6	910,694	1,130,742	1	1	4	19	25	3	3	6	44	56	65	66	61	59
*Gulf of Mexico	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....
Dist. 5: East Central	2	....	1	8	....	11	29	11	78,444	40	24	+ 66.7	179,127	135,908	1	....	....	6	7	1	....	1	24	26	12	10	15	6
Dist. 6: Northeast	38	....	2	18	....	58	85	55	321,731	143	131	+ 9.2	750,900	722,274	....	....	....	13	13	2	....	....	26	28	29	32	51	43
Dist. 7-B: North Central	87	....	14	71	2	174	177	199	536,916	351	403	— 12.9	1,148,104	1,290,501	3	....	1	36	40	9	....	4	97	110	137	100	97	95
Dist. 7-C: West Central	39	....	3	15	....	57	60	54	250,211	117	111	+ 5.4	518,655	470,064	....	....	1	12	13	2	....	1	30	33	33	72	77	66
Dist. 8: West	178	....	10	45	5	238	305	385	1,291,809	543	855	— 36.5	2,896,704	4,283,264	3	....	....	33	36	7	....	....	51	58	99	186	177	302
Dist. 9: North	120	....	18	86	....	224	204	263	629,747	428	563	— 24.0	1,236,450	1,600,634	2	....	....	26	28	3	....	....	62	65	81	113	128	166
Dist. 10: Panhandle	65	....	12	15	....	92	118	97	382,986	210	206	+ 1.9	944,719	1,022,140	....	....	....	6	6	....	....	....	17	17	30	83	79	88
Utah	10	....	1	12	....	23	12	21	136,347	35	55	— 36.4	195,287	327,332	....	....	1	10	11	1	....	1	18	20	22	39	45	46
Washington	....	....	....	1	....	1	....	....	8,520	1	....	....	8,520	....	....	....	....	1	1	....	....	....	1	1	....	....	1	....
West Virginia	9	....	56	5	....	70	68	59	174,319	138	117	+ 17.9	350,109	288,553	....	....	....	....	....	....	....	....	....	....	....	210	204	177
Wyoming	41	1	4	34	3	83	76	59	363,334	159	129	+ 23.3	745,904	689,161	....	1	1	18	20	....	1	1	48	50	53	75	107	77
Others	....	....	....	2	....	2	2	1	7,902	4	2	+ 50.0	22,607	5,738	....	....	....	3	3	....	....	....	5	5	2	4	6	8
Total United States	1,636	61	328	1,247	49	3,321	3,941	3,685	13,992,505	7,262	8,019	— 9.5	30,854,803	33,530,444	31	6	17	584	638	95	14	36	1,393	1,538	1,555	3,582	3,919	3,858
Total Western Canada	145	....	20	85	....	250	234	208	1,350,000	484	399	+ 31.2	2,649,525	2,058,775	....	....	....	....	....	....	....	....	....	....	....	241	234	253

* Gulf of Mexico wells are included in their respective district totals.

How Timken® steel became a string saver

YOU probably recognize the steel parts below as tool joints that hold together a string of drill pipe. Deep hole drilling puts a terrific strain on these joints. And a break is costly in both time and money.

Manufacturers came to Timken Company metallurgists to solve their breakage problem. Our experts studied the problem and recommended a special analysis of Timken seamless steel tubing.

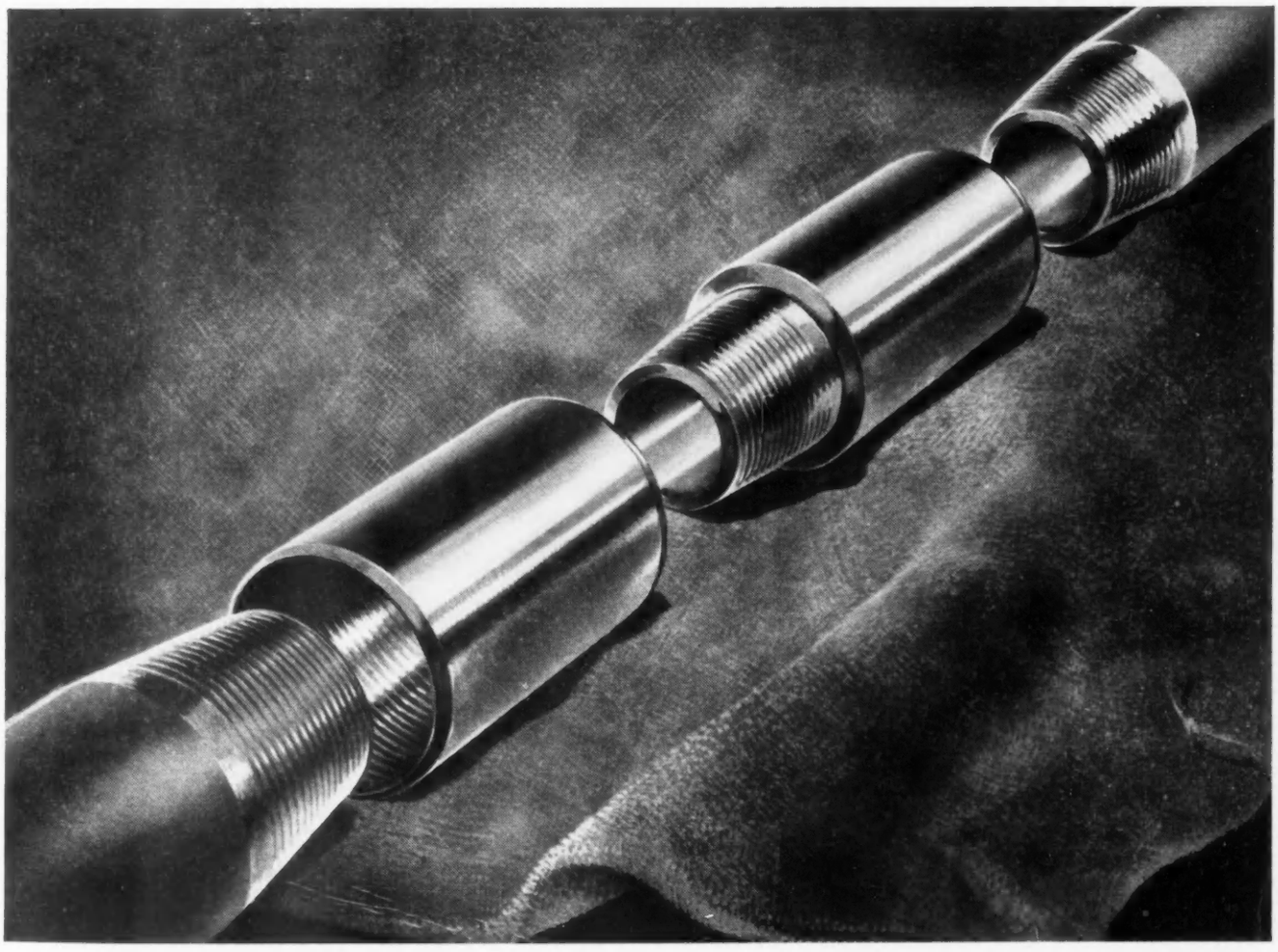
The manufacturers tested it. They found the refined grain structure and spiral grain flow of the Timken tubing gave joints the fine forged quality they need to resist string failure. Big economies in time and money resulted.

You'll also find Timken steel the most economical you can use for high-strength casing, drill collars, pumps, and refinery tubes and piping. Whatever the application, Timken steel tubing cuts production time and material costs—the hole's already there!

We've even developed a new high-strength oil well tubing that offers a yield strength up to 125,000 PSI —20% stronger than the stiffest API spec, 5A. Whatever your steel problem, Timken Company metallurgists are ready to help you solve it. Why not give them a call? The Timken Roller Bearing Company, Steel and Tube Division, Canton 6, Ohio. Cable: "TIMROSCO". *Makers of Tapered Roller Bearings, Fine Alloy Steels and Removable Rock Bits.*

WHEN YOU BUY TIMKEN STEEL YOU GET:

1. Quality that's uniform from heat to heat, bar to bar, order to order
2. Service from the experts in specialty steels
3. Over 40 years experience in solving tough steel problems



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TIMKEN ALLOY STEEL AND SEAMLESS TUBING IS AVAILABLE FROM WAREHOUSE STOCK IN 44 CITIES IN THE UNITED STATES

These are the wind swept mountains of coastal Alaska *where everything works against the geophysicists' summertime searches. Here, in the summer of 1959, one particular 20 man geophysical party moved with exceptional speed and safety. Why?... because a new Hiller 12E, operated by Livingston Air Service of Corvallis, Oregon, moved and supported them. This new helicopter doubled the payload any other light utility helicopter had ever been able to carry on identical jobs.*

Specifically, the 12E's typical payload was a two man survey team, all their equipment, and a 150 lb. drill, plus explosives. Multiply that by the entire 20 man team and you see why the head geologist and party chief called it..."the best helicopter buy in Alaska this summer."

In the arctic or the tropics, timberline or shoreline, the 12E's performance will pay off on important jobs in your operations–exploration, offshore taxi and supply, pipeline construction and many more.

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He invests *in the best aircraft available so* ***you*** *can have the convenience and economy of chartering by the flight or by the contract. It's worth looking into. You'll know right away whether the 12E will make substantial savings in your operation. Write today for free literature, "New Workhorse for Petroleum." Commercial Division*

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COMPLETED AS A PRODUCER . . .

BELOW 20,000 FEET

Had this well been dry, it would merely be another statistic. Yet, it was completed as a producer.

To prove production possibilities on this deep Louisiana well, five Drill Stem Tests were run below the 20,000 ft. mark. In each instance, the packers were set below 20,000 feet, making these the deepest Drill Stem Tests ever recorded.

Testing conditions were most severe. Throughout each test, bottom hole temperature was 426°, mud weight ranged from 18.2 to 18.4, with a viscosity varying from 50 to 60. During the five deep tests, Johnston equipment encountered and recorded formation pressures as high as 19,365 psi and hydrostatic mud pressures up to 22,045 psi.

Packers and other equipment have previously been run and set below this depth; however, none in a Drill Stem Testing operation, nor under the conditions encountered in this well.

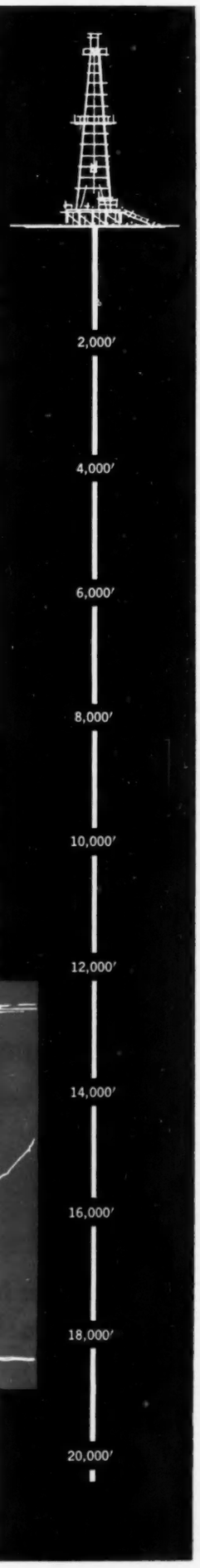
No misruns or equipment failures occurred. All equipment was retrieved intact. On two tests, equipment remained in the hole over twenty hours. Tests were performed in 7 inch—35 lb. casing through a 3/8 inch bottom hole choke. All were successful.

Drilling a well below 20,000 feet is a significant accomplishment, especially with the subsurface conditions peculiar to the Gulf Coast. The five Johnston Tests performed at this depth are also significant. They are testimony to the fact that Johnston can conduct Drill Stem Testing operations at extreme depths where high bottom-hole temperatures and extreme high pressures are encountered.

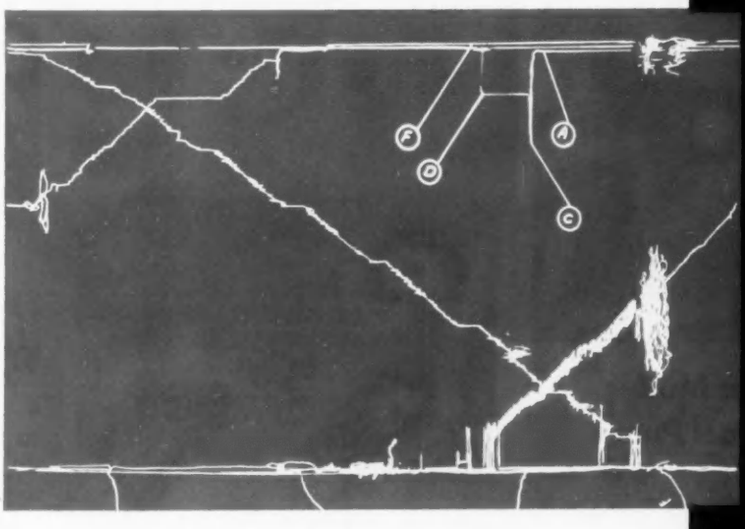
The drilling, testing and completion of this well is a prime example of the value of experience and planning, and proves the advisability of gathering all available information and data for evaluation prior to completing any well.

In any area . . . in any well . . . deep or shallow . . . high pressure or low pressure . . . before you set casing on your next well, call Johnston Testers. You get more from a Johnston test.

All tests were performed by Johnston Testers using the new Johnston testing tools.



FINAL TEST
Packer set at 20,068′
Initial Hyd. Mud 19,960 psi
Initial Flow 15,435 psi
Final Flow 17,719 psi
Final Hyd. Mud 20,061 psi
Recovery Oil (39.5° Gravity) and Gas



JOHNSTON TESTERS, INC.

P. O. Box 98 Houston 1, Texas

Practical Operating Hints

These How-To-Do-It Ideas Can Save You Money

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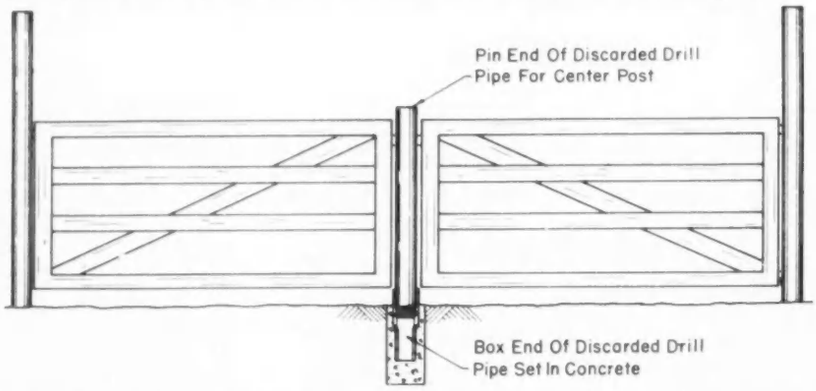
Build Wider Gate With Old Drill Pipe



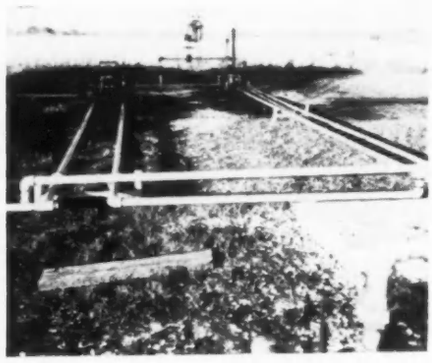
Discarded drill pipe can be used to build a road-width gate that can be used full width or one side at a time as the load demands. Many lease gates are not wide enough to accommodate rigs, tanks and other loads without damage to the gate proper. This double gate permits use of only one side for normal width loads.

Use a short length of the pin end of a section of discarded drill pipe for the center post. Cut this section of the pipe so that it is the height of the gate. Set a short piece of the box end of the drill pipe in concrete in center of the road bed. The length of drill pipe with the pin connection is then screwed into this box connection and serves as a sturdy permanent center post. When wide loads need to pass, unscrew the center post from the foundation and open both gates.

Condition Your Mud With Centrifugal Pump

When mud tanks are used on a drilling rig, keep the mud in condition by mounting a centrifugal pumping unit near the tanks, sucking the mud out of the bottom and to the top. The mud can be put through in a matter of moments since the centrifugal provides a high volume and the head is low.

To have a standby, the pumping units are doubled so that either pump can work from either tank, or two tanks can be mixed at the same time. Since the heavier mud settles at the bottom, these pumps pick it up at the lowest point and put it back on top of the mud tank, saving the wear and tear of an auxiliary reciprocating pump.

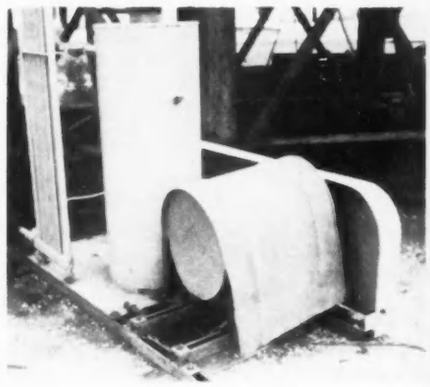


Above-ground Piping Makes Neat Hook-up

Above ground installation of all piping on a tank battery results in a neat appearing, convenient hook-up. All lines can be traced to their source and there is no guesswork as to the identity of each line in the battery. Valves also are above ground and are easily accessible.

Stripe Your Stairways As Safety Precaution

Paint the risers on rig stairs in a striped pattern as an added safety measure. Use contrasting colors as an attention getter. To further stress the importance of safety, post signs in conspicuous locations so that rig personnel will be "safety conscious."

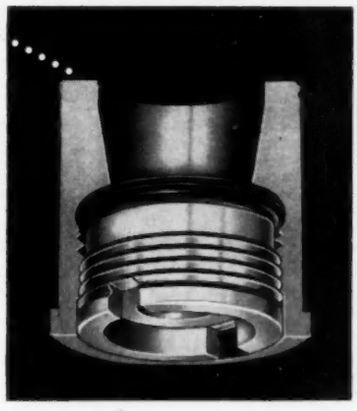


Split Chemical Drum Used For Engine Cover

Here's a unique engine cover which a South Louisiana operator devised to protect the prime mover of his hydraulic pumping unit. In this instance a small chemical drum was large enough to provide an effective cover.

The drum first is split length-wise. It then is cut approximately halfway around each end and the sides are pulled straight as shown in the photograph. The drum then is slipped over the motor and will provide protection.

Smith Threaded Flow Nozzle sectioned to illustrate O-Ring and general construction



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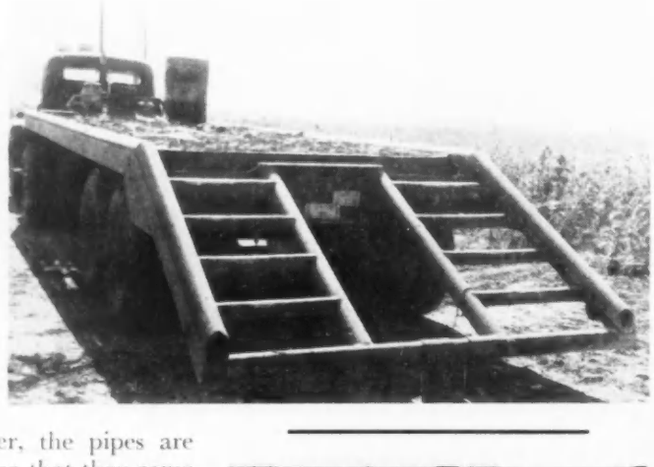
THE JET BIT WITH THREADED FLOW NOZZLES

For more data on advertised products, use Readers' Service Cards, last page.

Load Tractor Easily With Ramp

Where tractors are continually on the move in flat lands while rigging up and digging pits, a ramp fastened to the back of the semi-trailer makes it easy to load and unload the tractor.



The ramp is made from drill pipe and runs the entire length of the trailer along the sides. At the back corners of the trailer, the pipes are mitered and welded so that they come off at an angle to a point about 10 inches above the ground. A track frame is then built as shown. When in transit, the upright supports are swung up and fastened in place. When it is necessary to load or unload the tractor, the supports are put under the frame and the tractor is driven up or down off the trailer.

Construct Meter Stand From Scrap Tubing, Pipe

This meter stand is easily built from junk pieces of 2-inch tubing and 1-inch pipe which are usually found around most leases. The vertical portion of the stand (to which the meter is attached) is composed of the end of a joint of 2-inch tubing complete with coupling.

Three pieces of 1-inch pipe have been welded at convenient angles around the tubing coupling to provide a base for the stand. The stand can be used to support orifice meters, pressure recorders, etc. The stand can be used as a permanent or portable unit.

Weld Safety Stops on Edge of Stairways

Weld ¼-inch rods on the leading edge of stairways as a safety precaution in freezing or rainy weather. When the step is icy or wet, the rod will prevent slipping.

Can on the Lease Sign Keeps Pumper in Touch

A small can, attached to the lease sign at the lease entrance, will help in keeping track of a pumper who must travel around to check on scattered leases.

On days when supply men or other visitors are expected in the field, a note can be left in the can notifying them of the whereabouts of field personnel. If a pumper has to leave a lease unexpectedly, he can leave a message advising the visitor where he can be located.

If the supply man is running late and field personnel are busy elsewhere, requisitions can be left in the can so that the order can be filled as quickly as possible.

Air Compressor Provides Fresh Supply of Rig Water

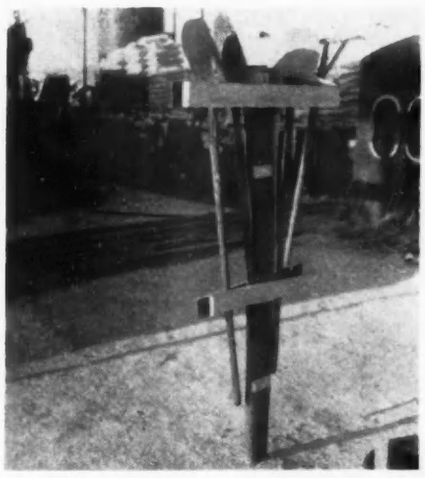
Rig an air compressor on a water well to provide a ready supply of fresh water to a rig. After the water well and pits are completed, case the well with one-inch tubing run to the bottom and a one-eighth jet in the bottom looking up. Run the casing to the pit and hang the one-inch tubing on a 3-to-1 bushing. Spot the air compressor a joint of pipe away from the rig and when it is connected, water is flowing into the pit in a matter of seconds. This assembly can be moved to the next location in one load.

Use Extended Handles On Over-Flow Valves

This Gulf Coast operator has installed over-flow lines between all

tanks in his tank battery so that pumpers will not have to be on hand to switch a tank when it fills. To provide control and permit strapping of the tanks to a maximum height, the extended handle gate valves shown were installed on each overflow line. If the pumper wants to take one or several tanks out of the overflow system, he simply has to manipulate the valve from the tank catwalk.

The extended handles provide a safe means for this operation since personnel do not have to walk out on top of the tank to close the valve with a regular wrench.

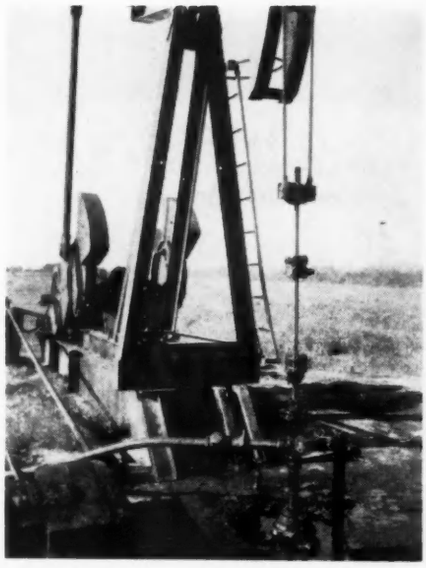


Centrally Located Rack Holds Shovels and Picks

A simple and centrally located rack for rig tools will contribute to good housekeeping practices. Set a 10-foot 2-by-6 post in a hole at a point that is readily accessible yet will not interfere with normal traffic. Nail two horizontal lengths of 2-by-4 material to the top of the post. Midway between the top and ground level, nail two 1-by-4s. Hand tools are hung in the rack as shown in the photograph. Such a rack will encourage replacement of tools when a chore is completed. Having tools stored at a central location will save time in emergency clean-up jobs.

Make Pumping Unit Base From Steel Walking Beams

An oil operator in Kansas uses discarded walking beams from standard rigs to provide a base for his pumping units. By using two beams for each unit, installations are rigidly supported when the beams are installed as shown. The unit is just high enough to allow the counter weights to clear



the ground. When a well is completed, several timbers are laid on the ground and the beams are installed cross-wise as shown.

The unit then is installed and tack welded to the beams. Notches are cut in the sides of the base beams to allow clearance for the counterweights.

No-Wall-Stick Drill Collars

The surface area of these drill collars has been changed to reduce wall contact area by more than 40%. Weight loss of the drill collar is only about 4%. Reduction of 40% in contact area results in a proportionate decrease in the total sticking force due to differential pressure of 40%. This design also gives a section of pressure equalization each foot along the body of the drill collar.

Three sizes (6", 4¾", 4⅛") of NO-WALL-STICK DRILL COLLARS are available on a rental basis in the Texas and Louisiana Gulf Coast area. Rental price of these NO-WALL-STICK DRILL COLLARS is very competitive to conventional drill collars run with stabilizers.

Any new or used drill collars, regardless of size, owned by Drilling Contractors or Oil Companies may be converted to NO-WALL-STICK DRILL COLLARS for a fixed conversion charge.

NO-WALL-STICK DRILL COLLARS offer far more protection from wall sticking in high angle holes or holes which have shale wash outs than drill collar strings using stabilizers.

NO-WALL-STICK DRILL COLLARS will not ball up, will not peel off wall cake, and may be sealed off by a Hydril type blow out preventor at any point.

Patent Pending

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No-Wall-Stick Drill Collars
effectively reduce sticking of drill collars

This new drill collar design has been expressly developed to combat the problem of differential pressure sticking of the drill collar string in the hole. It is a direct step in materially reducing the total sticking force.

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In some of the world's toughest assignments, the EXPLORER Model 8000 24-trace All-Transistorized Seismograph has effected reductions in recording personnel of 50 percent from the number required for the typical full range portable systems. Due to the reduced weight and number of packages for amplifiers, batteries and interconnecting cables, only seven men are required for the 8000 system. In foreign operations, the additional savings in manpower will be several times the number of packages eliminated due to release of support personnel.

Of most importance, it is reported that the decreased time involved at and between each recording set-up with the EXPLORER Seismograph has approximately doubled production, and, of course, cut the cost per profile in half.

Furthermore, the 8000 system is effective over a wide range of frequencies, from high resolution to refraction. You have a wide selection of AGC fixed and TVG gain controls.

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WORLD OIL'S SPECIAL 1960 EXPLORATION REPORT

Coordination to combine the effectiveness of different forms of geological and geophysical data is the most evident trend in exploration today. Seismologists and geologists are looking ahead to routine acquisition of stratigraphic data from seismic records. Sandstone cores are being oriented magnetically, and the positions of magnetic north are being determined from outcrops owing to past geologic ages. Gravity data and photogeology are being combined to boost the accuracy of both. Geochemistry, when coordinated with other exploration approaches, pays off. A new science, palynoloy, provides worldwide, interfacies correlations. And electronic computers help to absorb and coordinate all these data.

Coordination of geology and geophysics pays off

Combined use of geological, geophysical procedures is most evident current exploration trend

By A. T. Dennison, Head, Geophysical Section
BP Research Centre, Sunbury-on-Thames, England
Harry R. Warman, Vice President, Sinclair and BP Explorations, Inc.
New York City

As THE SEARCH for deeper horizons and in more obscure and inaccessible regions progresses, increasing use is made of geophysical methods of search for structures. With the search extending to geologically less well-known horizons, it becomes increasingly important to integrate geophysical results with geological knowledge, obtained if necessary by boreholes drilled purely for stratigraphic information and for measurements of velocity distribution, etc. Most changes in technique have been in geophysical methods and instrumentation, and some of these are outlined below.

It may seem a reflection on the methods of the oil industry in the past, but it is probably true that only recently has the need to integrate fully the methods and approaches of geophysics and geology obtained a satisfactory response. The need is, of course, mutual and stems from operating in areas where unknowns and difficulties are sufficient to require augmenting physical measurements with the intuitive approach of most geologists, who are more accustomed to providing answers to structural and stratigraphic problems from incomplete and indirect evidence.

TRENDS IN GEOLOGICAL METHODS

The need for new oil reserves has forced exploration into regions without oil indications, and where the very existence of suitable sediments

Courtesy PRAKLA

Courtesy PRAKLA

" . . . the instrument designers have achieved a high standard of reliability and portability: this is being maintained despite a tendency toward increased complexity in field equipment. Use of transistors may give some further improvements but certain technical problems remain to be overcome . . ."

Courtesy Sinclair Research Laboratories, Inc.

for oil generation and accumulation is unknown. It has also forced companies to operate in areas with great physical disadvantages. Geologists must now resort to new methods of transport such as "marsh-buggies," helicopters, and snow-tractors, not to mention the use of aqualungs to explore the sea bed.

Increasing use is being made of photogeology. In territory with difficult terrain, aerial photographs can be used to connect traverses made by geologists on the ground, and thus a map can be produced showing at any rate the main features of the geology. Aerial photographs can also be used to produce topographic maps both for planning ground reconnaissance and as bases for geological maps. The amount of detailed geology that can be obtained from air photographs varies with the climate and vegetation of an area, and also depends on the topography.

In arid mountains in the Middle East, complete coverage of overlapping photographs and checking by a few ground traverses can produce a geological map adequate for almost all purposes. Even in countries covered by tropical rain forest, much extremely difficult ground reconnaissance can be avoided by a few lines of aerial photographs coupled with oblique shots taken on both sides of the flight paths.

Offshore exploration. A considerable increase has taken place recently in the search for oil offshore. Geologically the sea bed is no different from the land except that it is obscured by water and usually also by recent sediments, i.e., sands, mud, coral, reef, etc. Where there is new sediment, geophysical methods are the only possible way of exploring the rock structures, but in some areas marine currents keep the sea floor clean, and attempts have been made to map and sample the underwater rocks by geologists using aqualung diving equipment and various types of sampling apparatus. As far as is generally known, such methods have achieved little practical results, and

the future prospects for this work are limited.

Although the oil industry is fully aware of the potential of the oil prospects of the continental shelves, concerted search has so far been almost entirely "step-out exploration" from adjacent land areas of rich production, as off Louisiana, California and Trinidad and in the Persian Gulf. Random exploration of unknown areas of submerged sediments will presumably proceed relatively slowly.

Overlooked onshore oil. In addition to increasing exploration in new areas, much attention has recently been paid to locating, within proved oil provinces, the undiscovered and smaller accumulations that have escaped previous exploration. These more obscure oil accumulations are largely dependent on changes of porosity and permeability within a reservoir series, on lensing of reservoir beds, and on unconformities. The search for these accumulations is not new. But a great deal more attention has been paid recently to careful analysis of all information from surface exposures, boreholes and geophysical work in order to determine geologic history and to predict thickness variations, facies changes, minor unconformities, etc. Detailed studies of the geology of areas require preparation of maps showing structure of the rocks at different depths and variations in thickness and lithology of various potential reservoir beds. There is thus an increasing demand for detailed cartography and draftsmanship, and the graphical-pictorial expression of variable factors.

Considerable attention is being paid to the long familiar problem of the source material of crude oil and the parallel problem of correlating types of oil with beds of particular type and age. It is hoped that research on these lines may produce evidence useful for allocating exploratory effort to more restricted parts of sedimentary basins, but at present such research has yielded little of practical value.

Exploration geology, in common with all geology concerned with the nature of rocks and the fluids they contain, makes increasing use of modern techniques that belong more properly to the realms of physics and chemistry. Both in survey work and more particularly in studies of reservoir rocks, considerable use is made of methods of mineral determination such as arc spectography, X-ray diffraction, and differential thermal analysis. The distribution of trace elements is sometimes used for the correlation of a succession of rocks in boreholes that cannot be differentiated by visual or electric logging techniques. The nature of the clay minerals in reservoir sandstones determines the best petroleum engineering procedures, and the above techniques play an essential part in identifying clay minerals.

Increasing use is made of fluorescence properties of hydrocarbons. In cuttings and cores from boreholes, potential reservoir beds are examined for fluorescence, and frequently chromatography is used to differentiate any hydrocarbons present. Despite the recent proving by dating with radioactive carbon that recent sediments contain geologically young crude oil, considerable attention is still paid, particularly by research workers, to surveying the hydrocarbon content of soils and near-surface rocks for hydrocarbon traces connected with deeper buried accumulations. Fluorescence and chromatography are particularly suited to this work. Surface mapping of hydrocarbons, however these are detected or analyzed, does not yet seem to be making a very valuable contribution to the discovery of new oil fields, and its prospects appear limited.

Geochemical research for geological purposes is being actively pursued by major American oil companies, some of which maintain large and expensive facilities for this work.

TRENDS IN GEOPHYSICAL METHODS

Problems facing the geophysicist have remained largely unchanged for a number of years. They can be summarized as follows:

- To increase the speed of operation in areas of difficult terrain
- To increase the accuracy and resolving power of geophysical methods
- To extend the use of the reflection method into "no-reflection" areas, since this method is the most accurate of those available at the present day
- To develop new methods which will give a direct indication of oil accumulation rather than geological structure.

Recent trends in geophysical methods can usefully be regarded as attempts to solve these problems. In the past five years some progress has been made in solving the first three, though not the fourth. Before discussing the various methods separately, some general comments on these first three points may be appropriate.

First, difficulties of terrain are not in themselves a primary obstacle to geophysical work. The instrument designers have achieved a high standard of reliability and portability, and this is being maintained in spite of the tendency towards increased complexity in the field equipment. The use of transistors may give some further improvements in this respect but certain technical problems remain to be overcome.

The recording equipment itself is only one of the items needed, however, and a number of improvements have been made in the heavier equipment required. Small and highly portable shot-hole drills have been produced for both man-pack and vehicle-mounted operation, and air drilling has been used in desert regions. Equally important have been the improvements in vehicle design, a variety of unusual types being developed in Canada to meet the special requirements there. The increasing use of helicopters has been a significant factor in speeding up geophysical work in many parts of the world, although in heavily-timbered areas their use is not as simple as it might appear.

In very difficult areas, the helicopter has appreciably reduced the physical strain on the geophysical crews and, apart from the improvement in speed of working, this should help to improve the quality of the data obtained. Nevertheless, geophysical work in such areas will always be much more costly than work elsewhere.

With the growing interest in deeper structures and in stratigraphic traps there is a continuous drive to improve the accuracy and resolution of geophysical methods. The use of seismic record sections and of the synthetic seismogram technique have been helpful steps to this end, and

" . . . the need for new oil reserves has forced companies to operate in areas with great physical disadvantages . . ."

there has been a better appreciation of the need for close velocity control in seismic surveys, particularly of the near-surface variations.

A considerable amount of research effort has been put into ways of obtaining workable reflections in the so-called "no-reflection" areas. This has resulted in improved methods of shooting, revised geophone patterns and, most recently, in the replacement of explosive as the energy source by a falling weight. It is realized however, that none of these methods can produce the required answer in every area. Each new area must be tackled as a separate problem, and fresh developments of technique merely increase the number of tools at the disposal of the geophysicist from which he must choose in planning his work.

The most striking of these new techniques is undoubtedly the widespread use of "broad-band" methods of recording seismic signals with facilities for later play-back and manipulation of the records. A very high proportion of seismic parties are now equipped with some form of magnetic tape unit for this purpose. A parallel (though basically distinct) development has been the use of unusual forms of presentation of the seismic data with considerable emphasis on variable-intensity and variable-area displays.

Magnetic surveys. Magnetic methods of prospecting receive only a limited amount of publicity in oil industry publications, but published figures of world-wide geophysical activity[1] show only a gradual decline in the use of this method. The data are, however, incomplete and since the figures do not completely distinguish between ground and airborne methods, they can be misleading. They do suggest that there has been some increase in the use of this method in the United States. This may well arise from an increasingly "regional" approach to exploration problems.

On the present view this method, measuring as it does primarily the effects of the basement rocks, is mainly useful in defining the shape of sedimentary basins. The results may also be used to indicate the depth of the sedimentary succession in these basins, and very useful information has been obtained in this way. The scope for this type of preliminary reconnaissance survey will clearly diminish in the future, but it may well be some years before this becomes apparent.

While recent instrumental developments in airborne work have not made any appreciable impact on magnetic surveys from the interpretation viewpoint, the nuclear precession magnetometer provides an alternative to the earlier flux gate type, and the Doppler navigation system may simplify the positioning of survey lines in areas lacking in topographical features.

Gravity surveys. The number of gravity parties rose gradually from 1950 to 1956, both in absolute terms and in relation to the number of seismic parties. It now appears to be declining at a slightly faster rate than the number of seismic parties. It is interesting to note that in the United States the ratio of seismic to gravity work in terms of crew months per year has remained at about 8 to 1 while that in the Eastern Hemisphere has changed from about 2.5 to 1 in 1955 to about 5 to 1 in 1958. Such a change is to be expected as surveys in new areas pass from the preliminary to the more detailed phase.

While gravity surveys have been extensively used in the past for preliminary reconnaissance work, particularly in view of their relative cheapness, it has become apparent that without a considerable amount of geological information on the area concerned, gravity surveys alone can give information which is either misleading or of doubtful value. Without information on basement depth or the density distribution of the sedimentary column, the choice of gravity anomalies as drilling sites must depend largely on their shape, since it is not known whether positive or

negative ones are of interest. In addition, there is always the possibility that the anomalies represent basement variations which are independent of the sedimentary succession.

For these reasons, it is usually considered that supporting seismic evidence is required before a gravity anomaly becomes a drilling site. Exceptions to this occur, however, when the probable geology and the type of target structure are known, and in such cases a gravity survey can be a cheap and useful tool. Salt dome structures provide an obvious example where gravity surveys can furnish at least a useful confirmation of the seismic interpretation.

Seismic refraction surveys. Apart from a temporary revival of interest in North America in the mid-1950s, mainly in "second-arrival" work, use of the refraction method has been largely restricted to the Eastern Hemisphere for many years. Here it has been used continuously by geophysical parties controlled from Europe and more recently by American companies as they take a rapidly growing interest in overseas territories.

Whereas the seismic reflection method is more accurate, the refraction method gives a much higher output in terms of miles per month, and is therefore particularly useful for locating areas which appear to justify more detailed work by the reflection technique. It can also be used, as it has been in West Texas and in Europe, for detailed work in areas where workable reflections are difficult to obtain. In such areas, much time can be wasted in finding the optimum reflection technique and it may be a better economic proposition to carry out a detailed refraction program.

The refraction method does, however, require the existence of a layer which has a considerably higher velocity than those above it and which *is conformable with the geological horizons of interest.* This restriction does not apply to the reflection method, although even here reflections must be obtainable either from the horizon of interest or from some conformable horizon.

Seismic reflection surveys. More than 80 percent of the geophysical exploration effort, in terms of crew-months, is devoted to the reflection method of prospecting; in terms of cost the proportion is considerably higher, since it is a relatively expensive method. The concentration on this method both in the field and in development research can, however, be justified by its accuracy and the amount of information it can yield. This is, of course, subject to usable field records being obtained, and in a number of areas this qualification is of considerable importance.

Where reflection quality is good, it is usually possible to plot accurately the contours of a number of geological interfaces, at depths ranging from a few hundred to over 20,000 feet. It is tempting to assume that the separate "reflections" seen on a record correspond to individual geological horizons, but recent work has shown clearly that in many cases *they are a composite signal formed by reflections from a number of closely spaced interfaces.*

Small changes in the spacing or nature of these interfaces can change the form of this composite signal appreciably, so that the reflections appear either to be discontinuous along a profile or to change their character. Even where these changes do not occur, considerable caution must be used in establishing the correlation between the reflection and its equivalent point in the geological succession, due regard being paid to the effects of the recording instruments on the apparent reflection time.

To assist in this correlation, "synthetic" seismograms have been widely used. These are seismic records prepared in the laboratory from a knowledge of the detailed velocity distribution in the ground, this information being obtained from a continuous velocity log run in a nearby borehole. Ideally, this synthetic seismogram should correspond very closely to the field records obtained in practice. It then becomes possible to isolate the effects of the various horizons on the field record. Owing to the assumptions which have to be made, the laboratory seismogram usually gives only moderate agreement with the field seismogram. However, the method has given very useful results and has been the subject of considerable research. It is of special interest in that it may prove particularly useful in locating stratigraphic traps.

"Thumping." The weight-dropping technique mentioned earlier is now in commercial use. The energy from a single drop of the weight is much less than that of an explosive charge and it is ordinarily necessary to combine the records from, say, 10 drops at different points to give an adequate signal-to-noise ratio. Using magnetic tape recording, a high rate of working has been achieved, but the main advantage of the system appears to be the avoidance of shothole drilling in areas where the terrain, or the number and depth of holes required, makes this drilling difficult and costly.

Recording methods. These two developments, while significant in themselves, have been overshadowed by the widespread changeover of many seismic parties to recording methods which are suitable for "playback." This does not signify any change in the basic principles of the method, but has produced considerable changes in equipment design and in field and interpretational procedures. The only system in widespread use is that using magnetic recording, and it is unfortunate that the simultaneous development of this method by a number of concerns has resulted in the field use of at least six basically different systems. Hence records can usually be played back only on the same type of equipment as that on which they were made. This can place geophysical contractors in a rather difficult position since each oil company prefers records which can be handled on its own playback machines.

However, two general types of equipment in use can be distinguished. In the first, playback facilities in the field are limited and the party depends on a central playback office for its detailed interpretation. The office machines are complex with full filtering, correcting and compositing facilities, and usually employ sequential playback of traces with a choice of final record presentation.

The second type of equipment has a small tape unit added to conventional equipment. This allows the party to obtain filtered and corrected playbacks in the field, sometimes in a form suitable for record sections. This system has obvious advantages for parties working in inaccessible areas, but the two systems are not

mutually exclusive and each has its own advantages.

Parallel with this development in recording technique, there has been a growing interest in the use of profile assembly in the final presentation of the records. In place of individual records corresponding to each shot point, records are assembled side by side with their datum times brought into coincidence and with each record reduced to about three inches in width. With the individual trace corrections having been made, reflections should line up both across each record and also from record to record across the profile. The profile thus has a strong visual similarity to a seismic cross-section and also to the corresponding geological cross-section. This similarity is only partial, however, in that no provision is made for migrating reflections when dips are encountered.

Profiles have the advantage of presenting a large amount of information to the interpreter in a most convenient form. In areas where faults and steep dips occur it may be possible to identify diffracted events and arrivals which cross the individual records at very steep angles. In areas of very variable reflection quality, the profile facilitates the "carrying-through" of reflections which may not appear on some of the records.

While "wiggle-trace" records can be used for this purpose, variable-area or variable-intensity records are usually preferred, since they allow a greater reduction in the individual trace width. It should be emphasized that such record sections do not contain more information than conventional ones—indeed the reverse is usually the case—but they do present the information in a way which makes it more apparent to the human eye. Apart from reducing the amount of computation, they present a maximum amount of information in a small space, and make it possible to defer the actual picking of reflections to a late stage in the interpretation process.

FUTURE DEVELOPMENTS

The foreseeable future of exploration reveals no likely revolutionary changes. The proven techniques may be used with more discretion and aimed at concentrating on the economically more attractive oil accumulations. The dependence on geophysical methods will almost certainly increase as the search becomes more and more confined to structures with no surface expression, but this will in no way diminish the need for geological appraisal of both the geophysical results and also those other characters of rock formation that determine the location of oil accumulations.

In geophysics there will doubtless be improvements in the semi-automatic data-handling machines, in the form of magnetic playback units, which are already in use. While digital computers are also in use to a limited extent, their application has developed more slowly than might have been expected. This has arisen partly from the nature of the geophysical computations and partly from the use of record sections. General opinion still favors the picking of reflections by a human operator rather than by a machine; record sections enable this picking to be done under the most favorable conditions, whereas the use of a digital computer normally involves the pick being made at an earlier stage in the data handling.

Nevertheless, it seems likely that computers will be used for the more complex calculations, and particularly for those involved in considering complex geological structures where a three-dimensional approach is essential. In such cases the record sections have only a limited application.

It does appear, however, that any major advance in seismic techniques will depend on a *better understanding of seismic wave propagation in the ground*. Considerable research effort is being put into this problem, and even relatively minor improvements in method could be well worthwhile. There is growing concern about the cost of geophysical methods, and with an estimated worldwide expenditure in petroleum geophysics of well over $200 million, any improvement may be economically important.

Until some new technique or fresh understanding of the mode of occurrence of oil is discovered, the existing pattern of exploration will continue. As far as is known, no current research appears likely to produce any revolution in technique, and oil exploration will continue as the familiar blend of speculation aided by geological appraisal and prediction, in their turn guided by geophysical methods of structural delineation. The major problem appears to be to achieve the required accuracy in surveys at the minimum cost, the accuracy required depending on the particular type of structure involved. Choice of the correct methods, both geological and geophysical, is essential, and it must be remembered that in this context apparent cost, as measured simply in dollars per month, ceases to have any real significance.

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How to make geochemical exploration succeed

Combined use of geochemical, hydraulic, geological, geophysical data yields good results

By Dr. S. J. Pirson, Professor of Petroleum Engineering
The University of Texas, Austin

SUCCESSFUL INTERPRETATION and understanding of geochemical anomalies, of their relation to origin, accumulation and migration of petroleum are essential to development of satisfactory concepts in geochemical prospecting.

The main concept of geochemical prospecting for petroleum is the belief that light as well as heavy hydrocarbon gases diffuse to the surface of the earth under the influence of pressure and concentration gradients. Tripp[1] has shown that this was thermodynamically possible, and (more recently) Sokolov[2] and Antonov[3] studied the process of hydrocarbon diffusion. Diffusion rates of hydrocarbon gases through water are of the order of 2.1×10^{-5} cm^2 sec^{-1}, whereas in clays and water-saturated shaly sands diffusion rates are considerably slower (from 10 to a 100 fold).

For a reservoir found at 10,000 feet, the rate of gas leakage would accordingly be of the order of 0.04 mm^3 per square foot per day through a uniform overburden of shaly sands and shales. However, rocks overlying oil and gas reservoirs are not homogene-

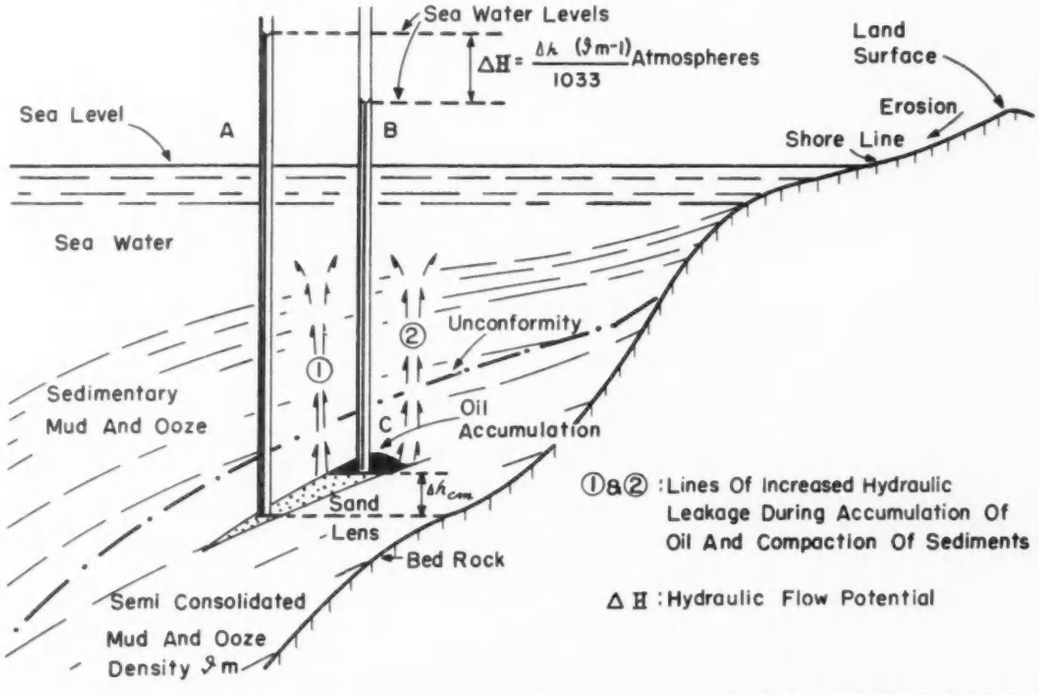

FIGURE 1—Illustrates formation of a stratigraphic trap and attendant hydraulic relationships, including leakage around the edges of the oil deposit as it reaches a mature development stage. According to the theory expressed, it would not be necessary for fracturing provided by structural deformation to cause escape of hydrocarbons, as may be common in the case of structural traps. Hence, geochemical exploration methods should be effective in finding stratigraphic as well as structural deposits. Success with geochemical methods indicates that this is so.

ous and they are commonly fissured and fractured; this renders the leakage pattern somewhat irregular but also of greater intensity. Russian scientists have observed that gas leakage surveys are most successful in regions of major tectonic disturbances where permeability has been increased due to fissures, fractures and faults in fissile rocks. Lesser amounts of trace hydrocarbons are found in the soil in relatively undisturbed sediments of the continental shelves.

According to Balk[4] the slow bending of rocks on the rim of geologic structures is responsible for the development of marginal fractures and joint fans. A rapid diastrophic movement would result in radial fractures over the structures. Gas leakage paths and distribution of hydrocarbon traces in the soil may accordingly depend on the rapidity of tectonic deformations, i.e., whether distribution will be zonal (in the form of a halo) or will show peak values at the apex of the structures.

Oil structures formed by differential compaction over buried hills or reefs may yield zonal marginal fractures and a halo distribution of hydrocarbon gases. Fractures and fissures providing gas leakage generally exist above unconformities or even successions of unconformities. Younger rocks at shallow depths often reflect the tectonic pattern of older rocks resulting from repeated rejuvenation by successive tectonic movements. It appears that macro- and micro-fractures are present over and around structural accumulations of petroleum, the trend and shape of which depend on the tectonic history of the region. Such fractures undoubtedly provide preferential migration paths for hydrocarbon leakage to the surface of the earth.

Records of oil field discoveries show, however, that diagnostic hydrocarbon leakage patterns are also associated with stratigraphic traps practically devoid of structural deformation susceptible of causing fractures and fissures (i.e., Little Beaver and Adena fields in the Denver-Julesburg basin surveyed by Horvitz). Mineralization patterns also have been found associated with such traps (i.e., the radiometric anomalies on the edge of the East Texas field).

Considerable evidence that hydrocarbon gas diffusion and leakage exist also in relatively undisturbed sedimentary provinces may be adduced from extensive studies (Buckley et al[5]) of formation waters in the Woodbine aquifer of East Texas, and in other oil provinces. Much gas is dissolved in formation waters; from 3 to 14 cubic feet of dissolved gas measured at standard conditions per barrel of water.

On the edge of the East Texas field, Woodbine water has substantially the same bubble point pressure (escaping pressure) as the undersaturated East Texas crude (740 psi). At Hawkins field a similar situation prevails, the bubble point pressure being 1,175 psi in both oil and water. However, the Hawkins crude in place is saturated whereas its associated water is not.

Most of the dissolved gas in oil field aquifers is methane but as much as 11 percent ethane in the total gas has been observed. The composition of solution gas in formation waters is substantially the same as that of natural gas produced from the same or from neighboring geologic formations. In the geologic provinces studied, it is significant that the estimated volume of natural gas in solution in formation waters is considerably *larger* than gas reserves from known oil and gas fields therein. The amount of gas dissolved in water increases with depth. This is significant in proving the escape of gases toward the surface by diffusion, a process dependent on the existence of a concentration gradient.

The general increase in ethane content with depth is of further significance. The fact that formation waters are generally undersaturated in solution gases is further evidence of continuing gas leakage; for when waters are saturated at formation pressure it is evidence that upward diffusion has stopped.

Hence, it appears that theories previously proposed to explain hydrocarbon leakage, concentration anomalies and mineralization distribution in the soil may be insufficient to explain both the association with structural and stratigraphic traps. Failure of geochemical prospecting to gain more support and to meet with more success in finding oil probably stems from the failure of geochemical theories to explain satisfactorily the origin of surface anomalies, i.e., anomalies of both hydrocarbons and mineralization regardless of the type of petroleum accumulation, structural or stratigraphic, and the relation of such anomalies in position, shape and intensity to the oil accumulations at depth.

GENESIS OF GEOCHEMICAL ANOMALIES

According to new concepts of formation of geochemical anomalies associated with oil and gas fields, they are viewed as *fossil remnants of past upward hydraulic leakage* from the bottom of sedimentary basins during their formation, compaction, uplifting and erosion. This hydraulic leakage took place mostly over the period of active sedimentation and compaction. Hydrocarbons of all kinds, salts derived from rocks (in particular radioactive salts), trace chemical elements usually associated with oil and gas (particularly iodine) in the process of generation, migrated upward with the waters in motion. Last but not least, change took place in environmental conditions from oxidation to reduction.

Genesis of geochemical anomalies over and around oil and gas fields while they were being formed is best illustrated by Figure 1. Here a marine basin is viewed to the left of a shore line. Detrital sediments are transported for deposition in the basin, subsiding under the burden of sediments. It is known from recent sediment examination (Smith[6]) that petroleum-like material is deposited together with sediments and ooze in sufficient disseminated volume to explain all the known oil fields of the world. All that is required to form an oil field is a process of migration, concentration and accumulation in suitable geologic traps.

Consider such a trap to be a buried sand bar or lens C made of relatively clean sand relative to the mud and ooze that encloses it. Now visualize manometers A and B (i.e., well casing) embedded in the sediments but terminated at their bottom in the clean sand lens. In each manometer clear salt water rises to such a height as to be in equilibrium with both hydrostatic and geostatic (overburden) pressures at the respective bottom of each well. The water level will be higher at manometer A than in manometer B because of the greater thickness of ooze and mud around well A, and particularly in view of the unconsolidated nature of the sediments and of their incompetency.

According to Darcy's law of fluid motion in porous media, a hydraulic flow of reservoir water will take place

from A to B within the sand lens. In so doing, this fluid contains countless tiny globules of oil. At the top of the lens, these globules cannot escape into the overlying ooze and mud because of its fine capillary size. The oil droplets are filtered out at the upper end of the lens because oil is the non-wetting phase and it would have to overcome a large capillary pressure gradient to re-enter the mud and ooze which eventually will become shale.

Hence, oil and gas accumulates at the top of the sand lens and this continues as long as the hydraulic flow is sustained. However, permeability to water no longer exists in the accumulated oil zone and hydraulic leakage is forced around the accumulation as shown in Figure 1. This oil accumulation process may be viewed as a revival of the Munn theory.[7] It appears as a very realistic explanation not only of oil and gas accumulation in stratigraphic and structural traps but also of mineralization effects that occur in unconsolidated sediments overlying developing oil and gas accumulations.

As formation water migrates around the petroleum deposit from greater to shallower depths, it cools and precipitates salts within the geologic section, *giving rise to a zonal distribution around the oil field.* Absorption of salts, ions and hydrocarbons may also play a part in this mineralization effect.

One of the most striking evidences of the vertical formation water leakage during consolidation and compaction of sediments is the low resistivity of the earth over salt domes even when buried more than 1,000 feet below the depth of investigation of surface resistivity measurements. Presumably, upward salt water migration around salt domes rendered the shallow formation waters more saline, thus resulting in lower resistivities (West[8]). Further evidence of upward water migration, partly in vapor form, is found in the higher salinities in a geologic horizon in depth, compared to lower salinities at shallow depths in the same horizon. Arbuckle waters attain 300,000 ppm salt content in the Anadarko Basin in Oklahoma at depths of 10,000 to 15,000 feet; in northeastern Kansas, Arbuckle water salinities of 2,000 to 3,000 ppm are observed at about 2,000 feet (Case[9]).

Hydraulic leakage around oil and gas accumulations explains the mineralization halo which geochemists heretofore have not explained satisfactorily. This halo may be evidenced at the surface in various ways, as follows:

- By increased radioactivity above background level
- By the presence of anomalous minerals and of mineral alteration products
- By anomalies in the transmission of radio waves because of variation in the dielectric constant of near surface rocks
- By variations in rock resistivity, in *oxidation-reduction potential,* in organic content, in bacterial population, etc.

Flerov[10] has shown that radioactive anomalies may carry to substantial depth by investigating the composite radioactivity of a number of wells in and around the Guselky oil field. He observed that the radioactivity of cores from producing wells was smaller than from wells immediately close to the edge of the field. It should be possible to use this observation in systematic geophysical prospecting for oil by gamma ray logging of seismic shot holes, of core holes and other well bores, provided the measurements are recorded on absolute radioactivity scales and that adequate corrections are made for hole size, mud density, tool eccentricity, type of rock, etc. The general procedure would be to integrate the gamma ray intensity curve over specified and properly selected depth intervals.

Additional evidence of mineralization around oil field is found in the *"induration of sediments" reflected by an increased drilling time* and reported on by Rosaire.[11]

Many proposed geochemical prospecting techniques for petroleum should find a ready explanation in the *"hydraulic leakage theory"* propounded here. It appears quite logical that Barret's radio wave profile method[12] responds to shallow conductivity and dielectric distribution contrasts which cause interference between a direct radio wave and a shallow refracted ground wave; this interference yields the "diagnostic anomaly" in the radio field strength intensity. Lasky's[13] thermal alteration of soil minerals (of clays in particular) finds its explanation in the unusual minerals that are formed in the zone of mineralization. The presence of heavy diagnostic hydrocarbons in near surface sediments and soils, the so-called "waxes" and bitumen may be nothing but micro accumulation of "paraffin-dirt" the significance of which was known at the turn of the century to be an index of oil. The search for surface occurrence of paraffin dirt was the first authenticated use of geochemical indices in the search for oil.

A distinct characteristic of surface indications of oil is their erratic and apparently random distribution. If the geochemical leakage of hydrocarbon gases and of formation waters were taking place in homogeneous, uniform and isotropic media from the point of view of permeability, porosity and grain size, it would be possible to predict definite forms, shapes and intensities for the expected geochemical anomalies. Geochemical methods, however, depend on discrete observations at selected stations which are limited in number. The resulting anomalies so obtained are bound to exhibit high degrees of erratic behavior. Even with virtually continuous sampling and measurement, as is done in continuous recording of gamma ray intensity, geochemical anomalies show an erratic distribution. Accordingly, it is *imperative to combine geochemical surveys not only with geological and geophysical information but also to combine geochemical measurements of diverse but supporting response.*

COMBINED GEOCHEMICAL SURVEYS

Combined gas and hydraulic leakage over and around oil fields leads to the recognition that certain geochemical observations respond with a maximum peak (in the absence of water table drift) right above the petroleum accumulation, whereas other geochemical observations respond with peak values distributed in a zonal fashion around the same accumulation. The two sets of observations should corroborate and supplement one another. In geochemical surveying it therefore appears advisable to make two sets of measurements, one responding to the peak over the structure and the other to the halo. In addition, because of the erratic behavior of the results owing to the nature of the geologic problem, it is advisable to make two independent measurements in each set.

Measurements responding to peak values over the oil field are as follows:

- Light hydrocarbon content of soils and soil air
- Light hydrocarbon leakage rate
- Population of hydrocarbon consuming bacteria
- Reduction-oxidation potential measurements.

Measurements responding to peak values on the edge of oil fields are as follows:

- Heavy hydrocarbon and bitumen mineralization of soil
- Radiometric measurements
- Trace chemical element mineralization
- Clay mineral alteration studies
- Radio wave interference pattern
- Resistivity measurements
- Drill time studies.

Such a combination of properly selected tests should contribute much to eliminate the apparent randomness of geochemical survey results, and would increase their already imposing degree of success in finding oil and gas fields:

Geochemical Surveys Incorporated of Dallas claims 25 discoveries out of 98 first class prospects surveyed from 1942 to 1957, 73 of which were drilled, for a success ratio of 34 percent.

Horvitz reports finding 109 geochemical anomalies over an eleven year period (1942-1953) of which 39 were drilled, yielding 23 discoveries, or a success ratio of 59 percent.

Sokolov[17] reports the success ratio of wells drilled on geochemical anomalies in the Soviet Union to be seven in ten when the surveys are made under favorable geological and geochemical conditions.

Development of geochemistry. Geochemical prospecting became a major effort of the Soviet Union about 1931, judging from the number of scientific publications in the USSR, and particularly in recent years. An idea of the magnitude of this effort may be had from the recent book by Kartsev et al.[18] There is presently a re-awakening in this country to the possibilities of geochemical prospecting, as evidenced by the interest shown at the General Petroleum Geochemistry Symposium held at Fordham University during the Fifth World Petroleum Congress, June 4, 1959 in New York City.

Geochemical prospecting appears to have been introduced in the United States by Rosaire[11] and Blau about 1935, soon followed by numerous investigators including Leo Horvitz,[14] Pirson,[15] Ransone,[16] Tripp,[1] and many others. Commercial use of the methods of geochemical prospecting flourished briefly in the U.S. immediately before and during World War II. Thereafter, such activity was almost altogether conducted by consulting firms, with a few major oil companies doing some fundamental research.

Geochemistry research, however, has become in recent years a major effort of most of the American petroleum research laboratories, not only for devising techniques of finding petroleum directly, but also for geologic age determination, source bed investigations, determination of processes of oil and gas migration and accumulation, oil origin, etc.

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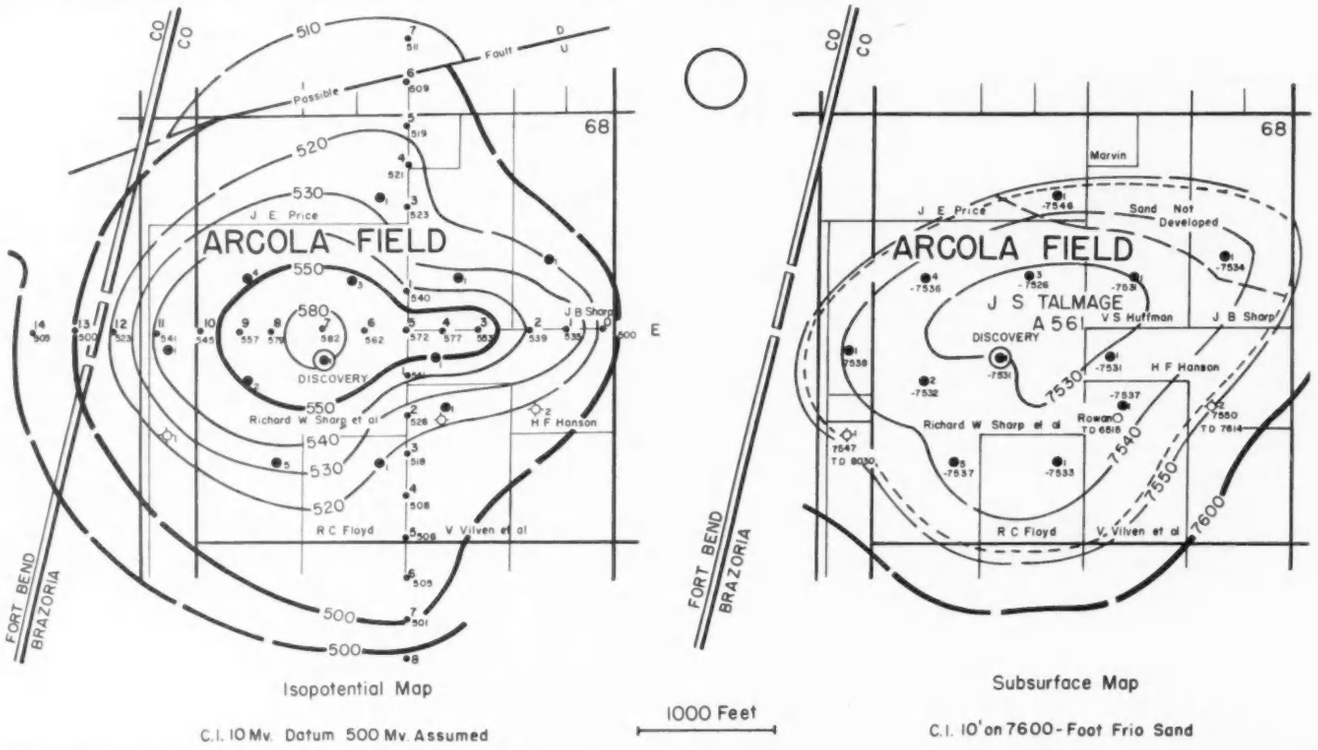

FIGURE 1—Isopotential map (left) and subsurface map contoured on the 7,600-foot Frio sand (right) in the Arcola field, Brazoria County, Texas. From maximum value of 582 Mv at approximate crest of structure, self-potential values decrease toward flanks.

Why sedimentary structures show high self-potentials

Earth's electrical currents operate by electrolysis and show anomalies on domal structures

By Orton E. Campbell, President
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PRESENCE OF A MINERALIZED ANOMALY, usually in a more or less halo-like pattern, associated with a geologic structure and/or an oil and gas accumulation, is supported by many years of surface geological and conjoined electrical current survey work. Evidence submitted by such geochemists as Rosaire, Merritt, Horvitz, Lasky and others also supports this relationship.

Critics of geochemistry raise the objection that an acceptable theory explaining the origin of the observed anomaly has not been offered. Insofar as the author is aware, this objection is valid.

The geochemical anomaly is a natural phenomenon consisting of a concentration of minerals in a halo pattern around or over a geologic structure and/or an oil accumulation.

This article is a theoretical one in the sense that it proposes an explanation for electrical anomalies measured in the horizontal direction at the earth's surface. BUT it is a practical one in that it argues from data believed to be entirely factual, based on the author's experience.

Any acceptable theory as to the origin of the anomaly must (1) identify and explain the operation of the natural agency, or agencies, transporting the minerals to the site of concentration, (2) show why such a concentration occurs around a structure and/or an oil accumulation and not elsewhere, and (3) account for the characteristic halo pattern.

The theory advanced is that one of the most important forces transporting the minerals, and the force determining the pattern, is supplied by electrical earth currents that flow because of a difference in the self-potential of the earth on and off geologic

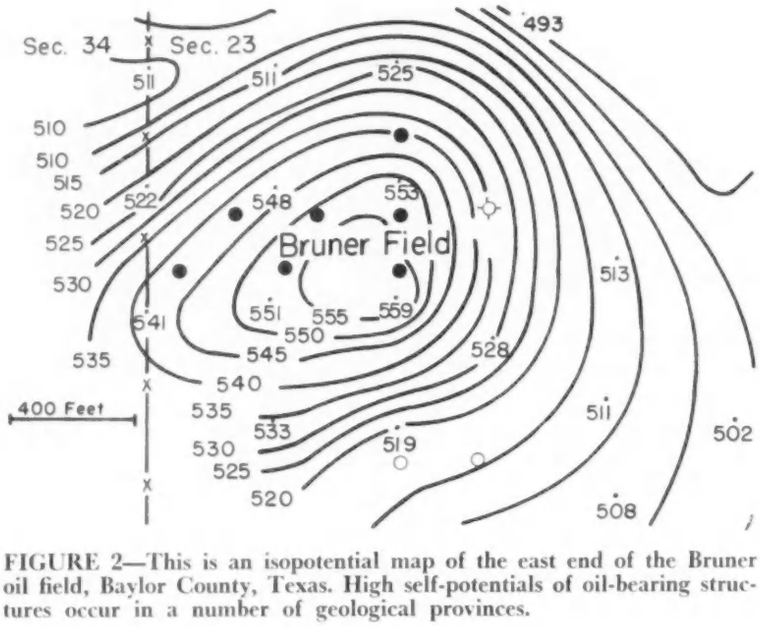

FIGURE 2—This is an isopotential map of the east end of the Bruner oil field, Baylor County, Texas. High self-potentials of oil-bearing structures occur in a number of geological provinces.

structures. The self-potential curves of electrical logs are compiled from data on these same currents.

If contact with the earth is made by two equi-potential electrodes, spaced at any desired interval and connected by an insulated conductor, a current may flow in the circuit formed half by the insulated conductor and half by the earth. This occurs when there is a difference in the self-potential of the earth between the two stations selected. Experience shows that there is a difference of self-potential when one of the stations is structurally higher than the other. If a sufficient number of stations are established along profiles or on a grid pattern, the outline and details of a geologic structure may be mapped on self-potential data.

In other words, a geologic structure is the site of an electrical field with the highest potential at the top and the lowest potential at the flanks. Experience shows that profiles of structure agree very closely with the same profiles on self-potential data. Empirical examples of this are found in Figures 1 and 2.

Given a difference of electrical potential on and off structure, and strata of various porosities carrying water impregnated with soluble mineral salts, natural electrolysis can and must take place. In this system the negative radicals, such as bicarbonates, would be transported toward the crest of the structure while the positive ions would be repelled toward the flanks. Hence, *earth currents, operating by electrolysis, are identified as a natural agency present and capable of producing the observed anomaly.*

Most structures are relatively flat on top and steep on the flanks. Since the potential profile agrees with the structural profile, the potential gradient will flatten around the edges of the top, the mineral transporting power of the earth currents will be lessened and most of the mineral load will be dropped around the top of the structure. In time, this peripheral area will become highly mineralized, its porosity will be greatly decreased and very little, if any, mineral material will reach the top area of the structure. The final result is the development of a local concentration of minerals in the form of a halo, or minimum, pattern over the structure. On the other hand, structures having a steep slope up to the crest might develop a maximum pattern.

The origin of the heavy mineralization observed by geochemists along fault planes may be explained by the fact that there is a sharp difference in self-potential between the high and low sides of faults. This is supported by the coincidence of profiles on minerals and self-potential across the trace of fault planes.

The theory proposed here has been applied to explain some stratigraphic accumulations. However, each stratigraphic pool is an individual problem depending upon local stratigraphy and lithology.

The hydrocarbon anomaly is thought to be determined by the mineral anomaly. Where fully developed the surface mineral anomaly is merely the surface projection of a mineralized vertical cylinder enclosing the accumulation. The ideal development of the mineral anomaly is found in fields where no water is present, but the producing formation carries salt water outside and adjacent to the field. It is suggested that the *hydrocarbon anomaly originates from migratory hydrocarbons* diverted upward by the mineral anomaly and *not* from hydrocarbons escaping from the accumulation.

It must be recognized that such agencies as hydrostatic and thermal forces may be the prime factors in mineral transport, but the nature of these forces alone do not account for the halo pattern. Apparently self-potential gradient is a balancing force which determines and preserves the characteristic halo pattern.

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About the Author

Orton E. Campbell is president of Telluric Exploration Company and of Fluorographic Exploration Company, Houston. A native of Dallas, he holds a B.S. degree in geology from Southern Methodist University. From 1929 to 1942 Campbell worked as a geologist for Sun Oil Company in southwest Texas, Mississippi, and other U.S. areas. Much of this experience was surface work. Since leaving Sun he has been a consulting geologist. He has widespread experience in surveying electrical currents in the subsoil as an approach to oil exploration.

Gravity-photogeology method boosts accuracy, cuts costs

Photogeology guides gravity surveys to verify indicated structures and avoid alluvial areas

By Virgil L. Whitworth,
Independent Photogeologist Associate,

Edward F. Haye, Geophysicist, and

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IN SOME AREAS the efficiency of gravity meter surveys can be doubled. Many areas have acquired a reputation for notoriously inaccurate gravimetric surveying coverage; these areas could be mapped more accurately. Large savings are to be had in avoiding following up non-structural gravity anomalies with more expensive methods of detailed geophysical surveying.

Gravity coverage too random. For example, in the Rio Grande Embayment of Texas, a conventional gravity map was compared with a photogeologic interpretation. In this region, al-

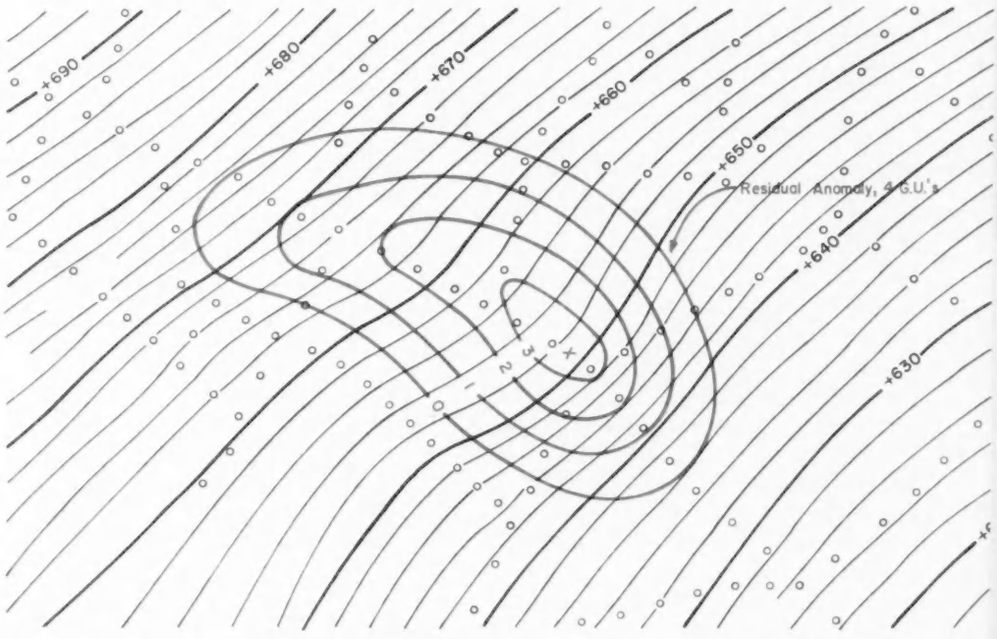

Figure 1A—A pronounced gravity anomaly in the Anadarko Basin in Oklahoma was the subject of a more detailed follow-up geophysical survey.

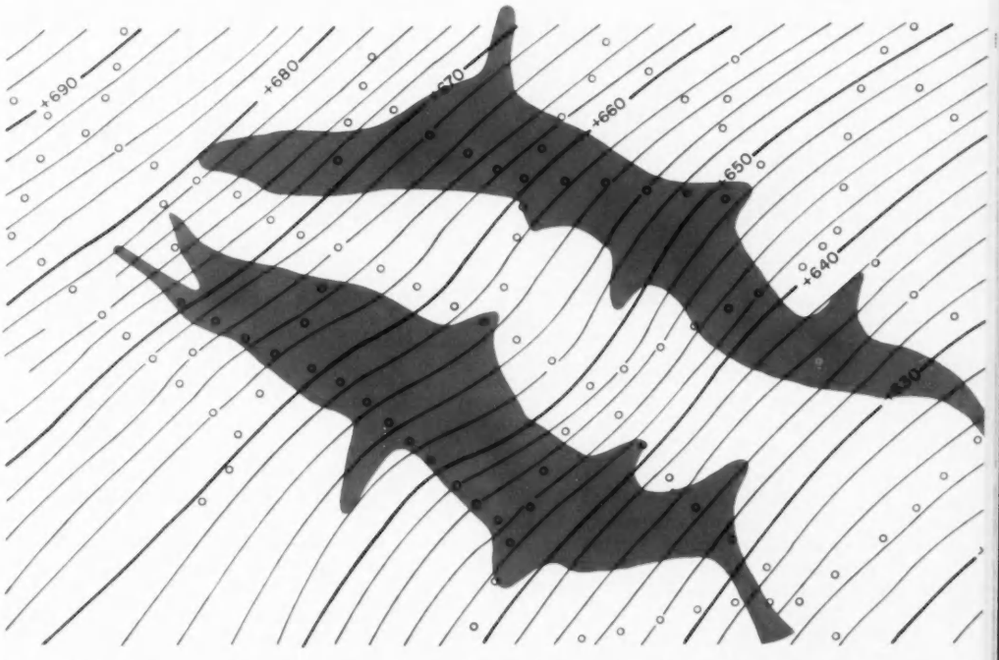

Figure 1B—Some gravity stations were located on relatively less dense alluvium (colored area). Lower gravity values obtained on the alluvium led to interpretation of an apparent positive anomaly. Use of photogeology and/or surface geology could have determined in advance the cause of this non-structural gravity anomaly, or could have prevented its development altogether by enabling gravity parties to avoid alluvial areas to the maximum extent. Advance planning can minimize or eliminate metering of alluvial areas in gravity surveys.

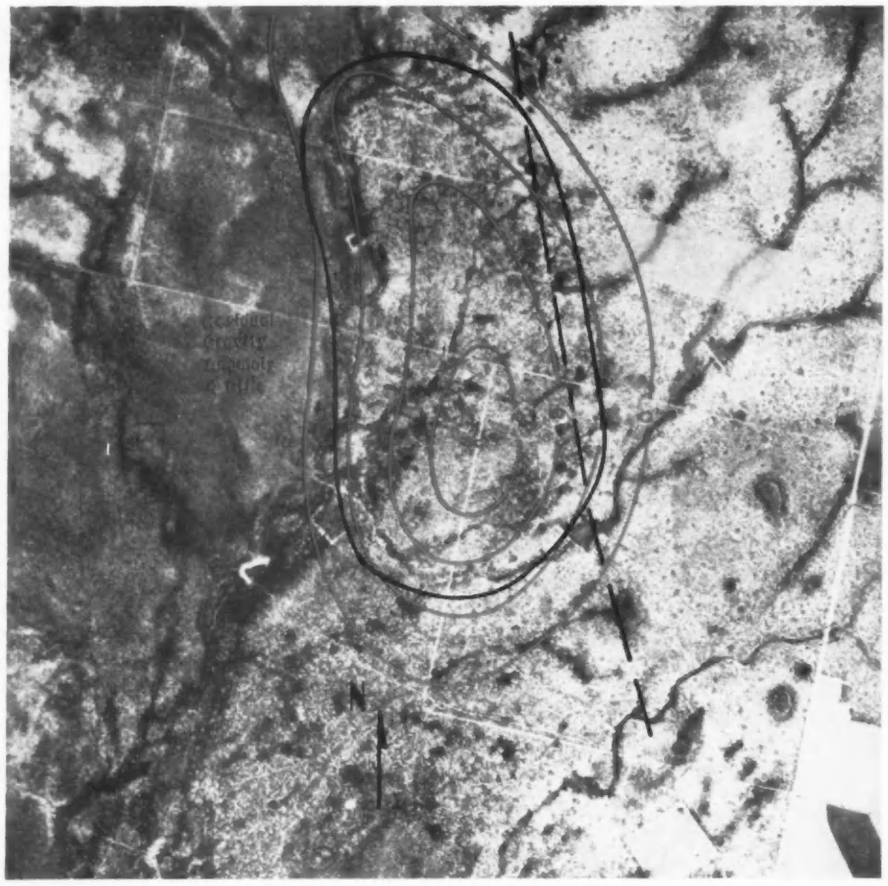

FIGURE 2—Photogeologic anomaly is indicated by awkward drainage bends on the north and south, and alignment of sinks to the east. Many oil fields show similar surface characteristics, even in very low-relief topography. Gravity surveys can follow up photogeologic interpretation, checking out anomalies. At the same time, crews can avoid alluvium areas determined in advance.

most all producing fields show some photogeologic expression. Photogeologic prospects were checked on the gravity map for confirmation. Only an estimated 35 percent of the photogeologic prospects had gravity station control across them. The other photogeologic prospects could not be further evaluated by gravity simply because there was no gravity station control present.

Planning specific coverage. By specifically planning gravity traverses across photogeologic features, many prospects can be found which might otherwise be overlooked.

Another example is taken from the Anadarko Basin in Oklahoma (Figure 1). One oil company undertook an expensive detail seismograph program to check a gravity anomaly. Seismic work determined that no structural feature existed. The gravity anomaly found its origin not at 8,000 feet of depth but above 80 feet, in the configuration of alluvium deposits.

The gravity survey was conducted without regard to surface outcrops. Metering was done at quarter-mile intervals along roads. The appealing positive gravity feature was flanked by negative gravity from meter readings taken on less dense alluvium deposited by streams crossing denser

Continued on Page 104

About the Authors

Whitworth

Haye

Lindholm

Virgil L. Whitworth is a photogeologist with widespread international experience. A native of Nevada, Mo., he holds a B.S. degree in geology from Missouri School of Mines (1923). His oil industry experience includes work for Roxana Petroleum from 1923 to 1926; Simms Oil Company, 1926-28; Henry L. Doherty and Company, 1928-30; Deep Rock Oil Company, 1930-31, and Continental Oil Company, 1936-42. Later he was consulting geologist to the Brazilian government, and pioneered photogeology in Brazil while with Drilling and Exploration Company there from 1946 to 1948. Since then he has been associated with a number of oil companies as consultant in West Texas, Canada, Alaska the U.S. Gulf Coast and other areas. During 1958 he worked as a consultant to Doeringsfeld, Amuedo, and Ivey, photogeologic contractors of Denver, Colorado. During World War II Whitworth was a captain in the U.S. Army Air Forces in photographic intelligence in the China-Burma-India theater.

Edward F. Haye, an experienced geologist and geophysicist, is president of Photogravity Company, Inc. He was born in San Antonio, Texas. He attended Trinity University and The University of Texas, and holds a B.S. degree in geology from the latter. He joined Standard Oil Company of Texas in 1951, working first in the San Antonio office before being transferred to Midland. Later posts with Standard included that of production geologist in Gainesville. His experience includes supervision of Standard's gravity field crew and analytical gravity and magnetic work.

Thomas M. Lindholm has experience in different types of geological and geophysical work. He is vice president of Photogravity Company, Inc. He holds a B.S. degree in geology from Texas Western College. His previous connection was with Standard Oil Company of Texas and The California Company. Lindholm worked in Standard's Midland office as a geologist from 1952 through 1955; as a seismic crew observer in Oklahoma and West Texas in 1956 and 1957; and in Standard's gravity section in Houston from 1957 to 1959. Later in 1959, he was with The California Company in Denver as head of the Gravity and Magnetics Department.

Palynology has important role in oil exploration

Varied microfossils study yields interfacies correlations, helps locate stratigraphic traps

By William S. Hoffmeister, Paleontological Group Leader
Jersey Production Research Company, Tulsa

PALYNOLOGY, now an accepted tool in oil exploration, includes microfossils that are useful in (1) making age determinations, (2) correlating wells and outcrop sections and (3) suggesting favorable areas for oil exploration by interpreting environment.

Oil company palynologists and academic workers are establishing stratigraphic ranges for these microfossils to generic and specific levels throughout the world. Groups of little-known microfossils are being studied by oil company research organizations to establish their particular usefulness in the oil industry.

USES OF MICROFOSSILS

Age determinations. Palynology provides a quick way of dating sediments. With improved processing techniques, microfossils are found in most lithologies. In dating a sample, scientists need not limit themselves to any one group of microfossils; if a sample lacks spores or pollen, it may carry hystrichospherids, microforams, chitinozoans, or some other recognizable group suitable for age determinations. Paleontologists formerly relied solely on foraminifera or some badly broken mollusks; the chances of encountering these in any random sample in the rock sequences are far less than those of finding groups included in palynology.

As research progresses and as more articles are published, more will be learned about the stratigraphic occurrence and geographic distribution on a world-wide basis for the many genera of microfossils.

Correlations. Palynology also helps in the correlation of subsurface and surface sections. Since these microfossils are encountered in almost all types of lithologies (less frequently in red beds and coarse-grained sediments),

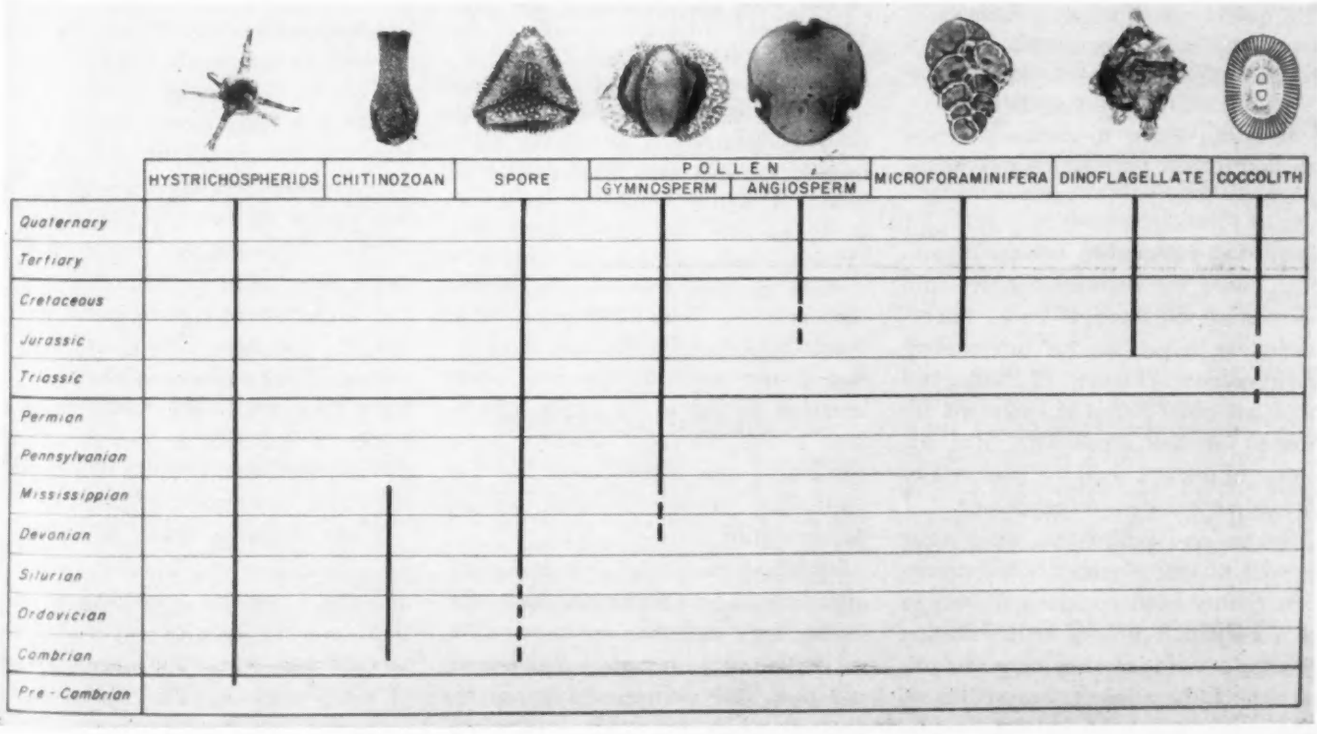

FIGURE 1—Stratigraphic ranges of some important microfossil groups.

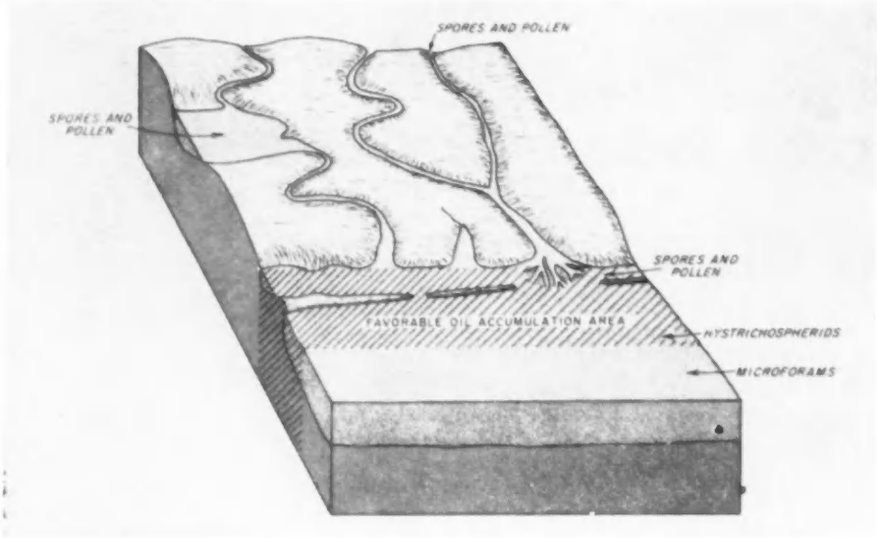

FIGURE 2—Schematic illustration of a modern shore showing the favorable habitat for oil.

they occur in most well and outcrop samples. There are several methods of correlating wells and outcrop sections by microfossils.

- If the same microfossil species are found throughout the wells or outcrop sections, histograms are set up based on population counts
- If new forms appear in the rock sequences, the first occurrences of some of the diagnostic microfossils will suffice for correlation
- Often good correlations are quickly established in formations of the same age merely by comparing relative percentages of animal over plant populations.

It is important to choose the best method for the particular fossil assemblage.

Outlining favorable areas. Besides being used for determining age and correlating sequences of rocks, microfossils are important for interpreting environments (Figure 2). Since oil pools are often found in sediments deposited on shelf areas paralleling the shores of ancient seas, the positions of the old shores should be known.

Spores and pollen are wind-borne as well as water-borne; thus population counts from composited samples of a particular unit of sedimentation reveal the relative proximity and direction of the ancient shores (Figure 3).

The value of spores, pollen, hystrichospherids, and other minute microfossils in locating the shores was first investigated using bottom samples from the Gulf of Mexico and the Atlantic Ocean. Spore and pollen abundance consistently decreased away from shore. Hystrichospherids were mostly confined to the brackish-marine sediments, while microforaminifera were notably more abundant in a marine environment.

The results of this investigation were applied to ancient sediments. Population counts of the spores were made from composited shale samples of the Morrow formation (Pennsylvanian age) from many wells in the Seminole, Oklahoma area. Isobotanical (equal spore population) lines indicating sediments containing the greatest abundance of spores were usually parallel and close to the oil fields. A similar study of spore assemblages of the Atoka formation (Pennsylvanian age) in the same area yielded identical results. The actual shorelines in both formations had been truncated by erosion. Population counts showed very few spores in areas devoid of oil pools. Therefore, it was concluded that the areas containing few spores were too far basinward to be favorable for oil accumulation.

Although oil pools are occasionally encountered in continental beds, the author feels that the best location for oil exploration lies in areas where *nearshore to brackish sediments merge with brackish to marine sediments.* Oil pools are generally scarce in the true marine sediments because of lack of reservoir rocks.

These microfossils can only indicate favorable areas for oil accumulation. Other geological and geophysical evidence must be relied upon for finding oil traps in these favorable habitats.

MICROFOSSILS USED

Microfossil groups most commonly used are plant spores and pollen, hystrichospherids and microforaminifera (Figure 1).

Spores and pollen. Plant spores are single-celled reproductive bodies of such non-flowering plants as ferns; pollen grains are one- to several-celled male reproductive bodies of flowering plants. Most spores are morphologically characterized by sutures that are openings through which germination takes place. A great majority of pollen grains have pores and furrows that are associated with germination.

The two groups of pollen grains are gymnosperm pollen, from plants that produce exposed seeds (not enclosed in a fruit); and angiosperm pollen, from plants that produce enclosed seeds in a fruit. Among the gymnosperms are the cedars, pines, and spruces; the angiosperms include such plants as oaks and roses.

Hystrichospherids. These are generally spherical to triangular bodies with spines, although many forms included in this group have smooth spherical to spindle-shaped bodies. The average form measures about 50 microns in diameter. These acid-insoluble organisms are important because they occur in sediments ranging from the late pre-Cambrian to Recent and show morphological changes *throughout* geologic time. Since they are found mostly in sediments of brackish to marine origin, the paleoecologist can use them in interpreting environment.

Little is known about the biological affinities of the hystrichospherids although it can be demonstrated that some are the eggs of copepod crustaceans and others the resting stages of dinoflagellates. They may represent also the reproductive cysts of desmids (algae) and the reproductive

bodies of bryozoans (tiny marine animals).

In oil exploration these minute microfossils may be especially useful in *reef reservoir rocks*. They seem to be fairly abundant here and in the adjoining sediments. In cases where forms differ with respect to their relative distance from reefs, they help outline the approximate positions of reefs.

Microforaminifera. These small organisms (average 70 microns), found in Jurassic to Recent rocks, are being used more and more by oil company palynologists. Although the forms with arenaceous shells are destroyed by the processing acid (hydrofluoric), forms with calcium carbonate shells are not; they are converted to calcium fluoride. It is still unknown whether microforams represent one stage in the life cycle of foraminifera, or whether they are merely size variants of forms with great size ranges. Where abundant, they generally represent a true marine environment and they are especially useful for correlations and age determinations. They usually indicate environments unfavorable for oil accumulation.

Little used microfossils. Among the lesser known and therefore little-used groups of microfossils currently receiving attention among palynologists are dinoflagellates, coccoliths, discoasterids, chitinozoans, desmids, and nannoconids. These are believed to have excellent potentialities for solving geologic problems. Probably the most important are the dinoflagellates, coccoliths, and chitinozoans (Figure 1).

Dinoflagellates. These are microscopic (25-125 microns in length) planktonic organisms with a globular body that is often covered with an acid-insoluble wall of cellulose. An equatorial furrow is usually present. The surface may be divided into polygonal plates and ornamented with spines. Some palynologists consider them to be algae while others think they are protozoans. They are found from early Jurassic to Recent times and have been useful for making world-wide correlations and age determinations. Some oil companies are doing research on these important microfossils.

Coccoliths. These minute planktonic organisms have spherical bodies, the coccospheres, that are covered by numerous calcareous plates (2-20 microns in diameter). These tiny plates generally separate from the body upon death of the organism and are often preserved in the sediments. These plates have been reported from rocks as old as the late Permian, but the earliest known rocks containing them in abundance are of middle Mesozoic age. Palynologists are now examining marine sediments all over the world, in order to determine their potential as a stratigraphic tool.

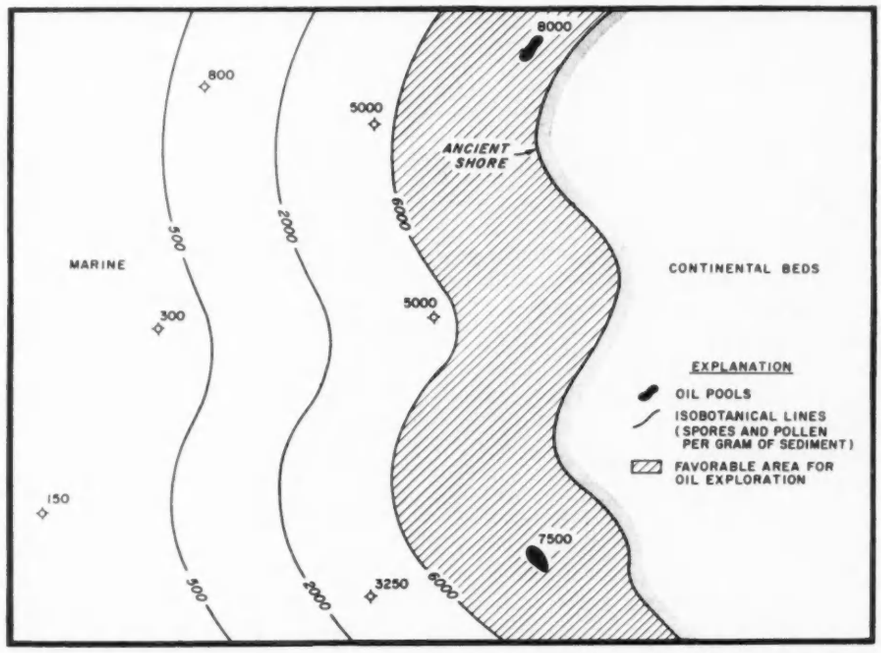

FIGURE 3—Schematic illustration of the favorable area for oil in an ancient depositional basin.

Chitinozoans. Chitinozoans are hollow membranes of various shapes, composed of chitinous material, and occur in marine rocks of Cambrian to Mississippian age. Their biological affinity is unknown. These forms, among the largest included in palynology (50-1,000 microns), are extremely helpful in dating Lower and Middle Paleozoic rocks that generally carry few microfossils such as plant spores.

EXTRACTION TECHNIQUES

Published methods of microfossil preparation naturally differ with the character of the rocks in which the organisms are entombed. A recent article by Funkhouser and Evitt, (*Micropaleontology*, July 1959) describes several methods that Jersey Production Research Company uses for samples containing acid-insoluble microfossils. The general method is outlined briefly here:

- Treat sample overnight with hydrofluoric acid (HF) (52% solution)
- Wash sample free of HF. Centrifuge 2 minutes at 3,000 rpm
- Oxidize with sodium hypochlorite (the Heard method)
- Treat with ammonium hydroxide (NH_4OH)
- Separate with heavy liquid (zinc chloride or zinc bromide); centrifuge in bent plastic tubing 15 minutes at 2,000 rpm
- Clip off top of heavy liquid separation; transfer to 100-cc centrifuge tube. Add water; acidify with about 1 cc of dilute HCl (just enough to dispose of the hydroxide formed when water is added to the zinc chloride or zinc bromide solution in the test tube). Centrifuge at 3,500 rpm for 5 minutes; wash with water until free of acid.

In processing coals, the Heard method is recommended. It differs from many published methods only by substituting a 5.25% solution of sodium hypochlorite for other oxidizing agents. This method was described by the writer in Oklahoma Geology Notes, Vol. 20, No. 2, 1960.

GROWTH OF PALYNOLOGY

The term palynology was originally limited to spore and pollen research, but many paleontologists including the author now use it to include other

minute plants and animals or their parts in the same size range, capable of being fossilized.

The word palynology, coined from the Greek verb *palyno* meaning "to scatter or distribute", was introduced in 1944 by H. A. Hyde and D. A. Williams. The average size of the organisms embraced in palynology is about 50 microns; they seldom exceed 150 microns. They are particularly useful in the oil business because of this small size. Enclosed within small particles of rock they readily escape the destructive action of the bit. They are even found in the dust material produced by air drilling.

Probably the first person to observe fossil spores was Henry Witham, who in 1833 described spores from thin sections of bituminous coals in England. Credit for first isolating fossil plant spores and pollen by chemical maceration of coals goes to Franz Schulze (1855). Spores and pollen were used to correlate coal seams long before they were used in the oil business. In the earliest non-industrial use, they were employed to interpret the climatic changes during the Quaternary period.

Probably the earliest known application of palynology to the petroleum industry was in 1938, when Royal Dutch Shell engaged Dr. R. Potonié, a German specialist on spores and pollen, to do some experimental work in Europe.

Spore and pollen work done in 1946 by Dr. L. R. Wilson (now at the University of Oklahoma) was probably the first for a United States or Canadian oil company. As a consultant for The Carter Oil Company, Research Department, he successfully correlated two wells located about 15 miles apart in east Texas solely by palynological means. Mrs. J. Wyatt Durham's 1945 work on spores and pollen for the Tropical Oil Company in Colombia was probably the first of its kind in South America.

Evidence of the importance of microfossils in oil exploration is the recent rapid growth of palynology in the industry. In 1947, for example, of the 26 spore and pollen investigators in the United States and Canada, only one was employed by an oil company. In 1954 there were 61 spore and pollen workers in the United States and Canada, and five were with oil companies. At the present time approximately half of the 100 or more palynologists in North America are full-time oil company employes.

Corresponding increases in the number of oil company palynologists have undoubtedly occurred in other parts of the world. According to Professor G. Erdtman of Sweden (personal communication, 1958) Russia now has 1,000 workers in palynology, 90 percent of whom are women. Recent Russian literature emphasizes the important role palynology is playing in industrial research.

ACKNOWLEDGMENT

The writer wishes to thank Jersey Production Research Company for permission to publish this article and his colleagues at the Research Center for reading the manuscript and offering valuable suggestions.

About the Author

Dr. William S. Hoffmeister is one of the most prominent authorities on palynology, having spent many years in this line of research. A native of Baltimore, Md., he holds B.A. and Ph.D. degrees from Johns Hopkins University. He did paleontological work for Creole Petroleum Corporation in Venezuela for 15 years before being transferred to The Carter Oil Company in Shreveport, La., in 1941 for similar duties. Since 1946, Dr. Hoffmeister has been engaged in paleontological research with Jersey Production Research Company in Tulsa, where he is currently group leader of the paleontological staff.

Gravity-photogeology boosts accuracy, cuts costs

(Continued from Page 100)

Permian shale. Reasonably accurate estimates of the thickness of the alluvium were later made from the gravity map. In this instance, coordination of photogeology with gravity could have avoided expenditure of large sums of money.

Density changes or masses closest to the gravity meter affect it most critically, by the inverse of the square of the distance, in accordance with Newton's Laws. These near-surface density changes can cause anomalies of the same size, shape, and amplitude as deeper subsurface structures.

A photogeologist can readily outline alluvial deposits and advise the gravity field party to avoid such areas in locating stations. If it is essential to place some stations on alluvium in order to gain adequate control, an average alluvium correction can be added to station values so obtained. This tends to remove potential misleading gravity anomalies. A knowledge of leached-out areas, sinks, and particularly of formation changes is essential to accurate gravity mapping. Surveying and computations should be adjusted consistent with lithologic density changes.

With cost-cutting and increased efficiency becoming ever more important in the oil exploration picture, coordination of gravity with other relatively inexpensive exploration tools and methods is a natural development. Heavy emphasis is being placed on gravity and photogeology. Interpretation of stream, vegetation, and fracture patterns and other similar features from aerial photographic mosaics has become an effective means of guiding oil exploration. The accuracy of this method and also of the gravity approach is being improved by combining both.

For instance, in shallow basement areas a gravity anomaly can easily be caused by a mass of denser igneous material within the basement. However, if the anomaly correlates with a photogeologic suggestion of structure, e.g., a suggestive fracture pattern, halo effect, an appealing drainage pattern or any other geomorphological structural indication, the likelihood of no structure being present is greatly reduced.

Hence, integrating gravity with photogeology is technically and monetarily beneficial. As these case histories show, coordination pays large dividends.

Electronic computers aid many exploration phases

Electronic data-processing gear useful in mapping, log interpretation, and gravity work

By Edward J. Assiter, Petroleum Representative
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Editor's Note: At first glance, this article on applications of electronic computers to exploration might not appear to bear any relationship to palynology, also being covered in thorough fashion in this issue of WORLD OIL. But—if one considers all those billions of polospores distributed and preserved during the 400 or so million years that plant life has existed—and also considers the thousands of polospore classifications and assemblages to be determined, it seems likely that much of this vast body of statistical work might be done with computers.

THE USE of electronic computers as applied to petroleum exploration is becoming more widespread as new applications continue to be found and developed. Although it is not generally expected that computers will actually replace geologists or geophysicists for any particular function, it is probable that in many cases those who improve their work output through use of available computing and other automatic data-processing equipment will enhance their chances for advancement.

This article has been categorized into five general exploration topics. They are geological mapping, log interpretation, statistical property evaluation, reflection seismograph data interpretation and gravity data interpretation.

GEOLOGICAL MAPPING

Exploration and development map construction consumes a major portion of time assigned such projects. Hence, many informative mapping possibilities in an active area are neglected due to work load restraints. A flexible and compact program to plot geological, geophysical, and land survey maps has been developed, utilizing automatic data processing equipment.

The geological phase of the routine is capable of performing computations

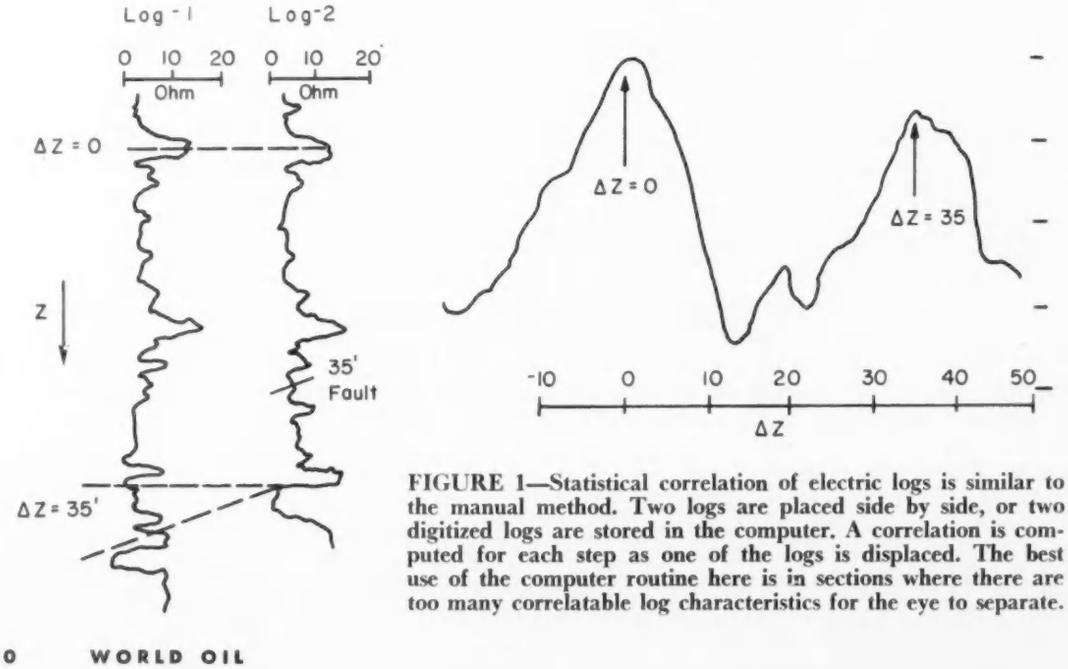
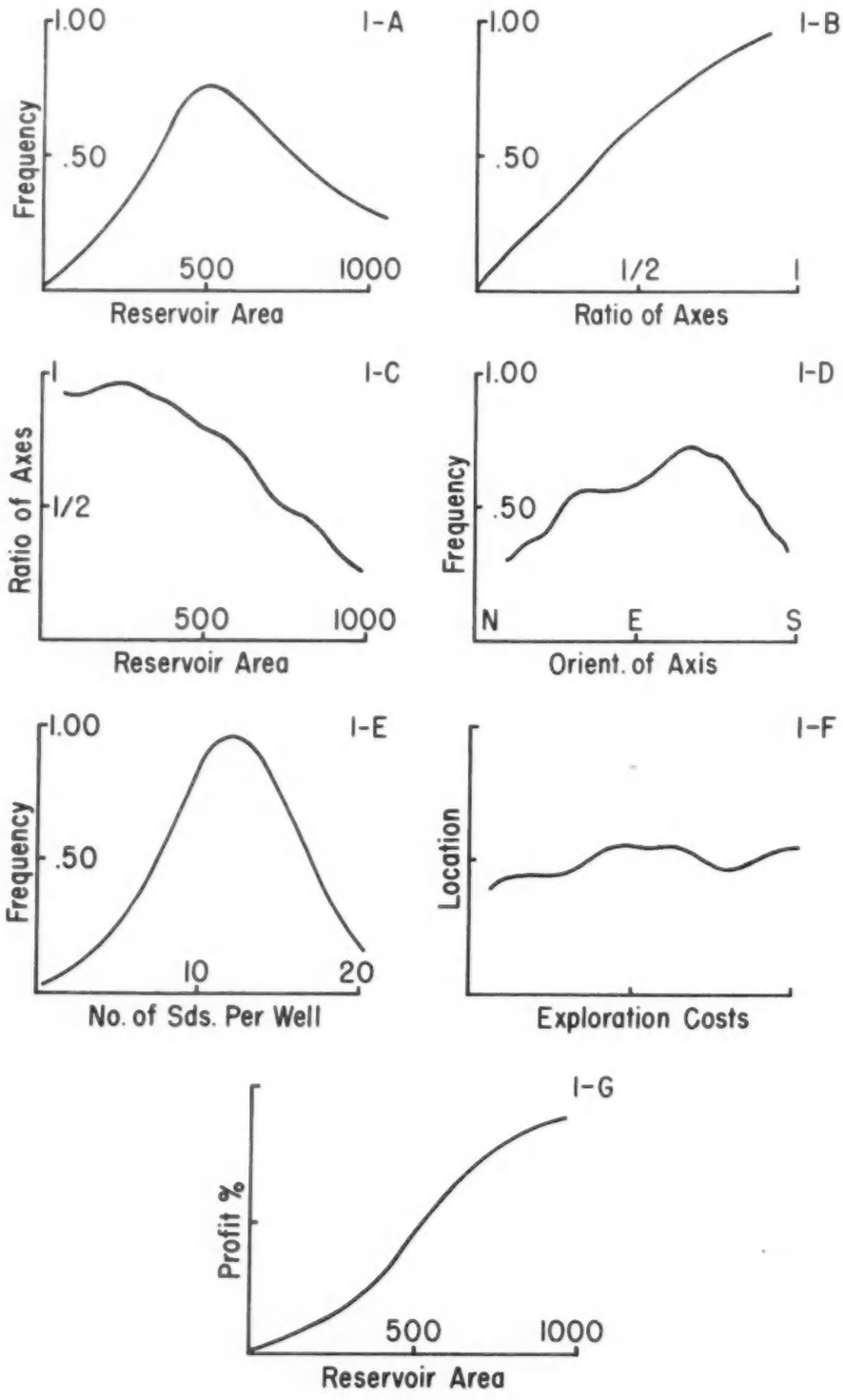


FIGURE 1—Statistical correlation of electric logs is similar to the manual method. Two logs are placed side by side, or two digitized logs are stored in the computer. A correlation is computed for each step as one of the logs is displaced. The best use of the computer routine here is in sections where there are too many correlatable log characteristics for the eye to separate.



Statistical Exploration

FIGURES 1A-1G—Evaluation of large properties or concessions assumes that an area can be proven by grid or pattern drilling. To determine parameters, available statistics are summarized in the form of distribution functions. A sequence of steps is indicated here to evaluate all known pertinent data as to the size, shape, orientation and distribution of potential reservoirs. In Figure 1A, the complete set of reservoirs is classified as to horizontal area against the frequency of occurrence of each size. Data are developed on frequency-shape distribution (1B), shape-area distribution (1C), frequency-orientation distribution (1D), frequency [potential reservoir sands per well] distribution (1E), drilling and lease costs (1F), and expected rate of return from reservoirs found (1G). More refined geological and geophysical data are admitted to the problem to modify the grid pattern and yield optimum drilling locations.

necessary for depth, isopach, and ratio maps. Provision is made for addition of subroutines to the program for any other type of geological map desired. A symbol is plotted to indicate position of assignment of up to ten words of 5-digit alphanumeric information above or below the symbol; e.g. well name, rotary table elevation, depth, test data and sand thickness. The type of map and scale desired is indicated by a header card to the data deck.

Input to the program must include a scale factor for the map, original and final coordinates, and any data necessary for the computation of the map desired. The output cards serve as off-line input to the special map-plotting routine. In addition, the original and final coordinates are plotted with the coordinate values. If the proper paper is selected for the plotting, it will serve as a base map for contouring.

Operating time for the medium-speed electronic computer is determined by the amount of information desired at each point plotted. If an average of four words of alphanumeric information is plotted for each point, the process rate is approximately 40 to 50 points per minute. This output is greatly increased if magnetic tape is the computer output and tape-to-card conversion is used.

LOG INTERPRETATION

The more popular uses for electrical, radioactive and velocity logging include the following: bed detection and definition; correlation; porosity, saturation, and oil water contact determinations; gas-oil contact (neutron); estimation of permeability, and in some cases the determination of the maximum producible oil index.

These quantities are not represented directly by the curves on the logs but must be inferred from the shapes and magnitudes and relationships of the curves. Prior to log analysis some of the curves must be corrected for undesired borehole factors.

The two approaches to interpretation and correction of logs are qualitative, and quantitative, analyses. Qualitative analysis is by far the more frequently practiced by geologists, but with the renewed emphasis on the evaluation of every potential reservoir in a well and the search for previously overlooked reservoirs, the quantitative approach is becoming more at-

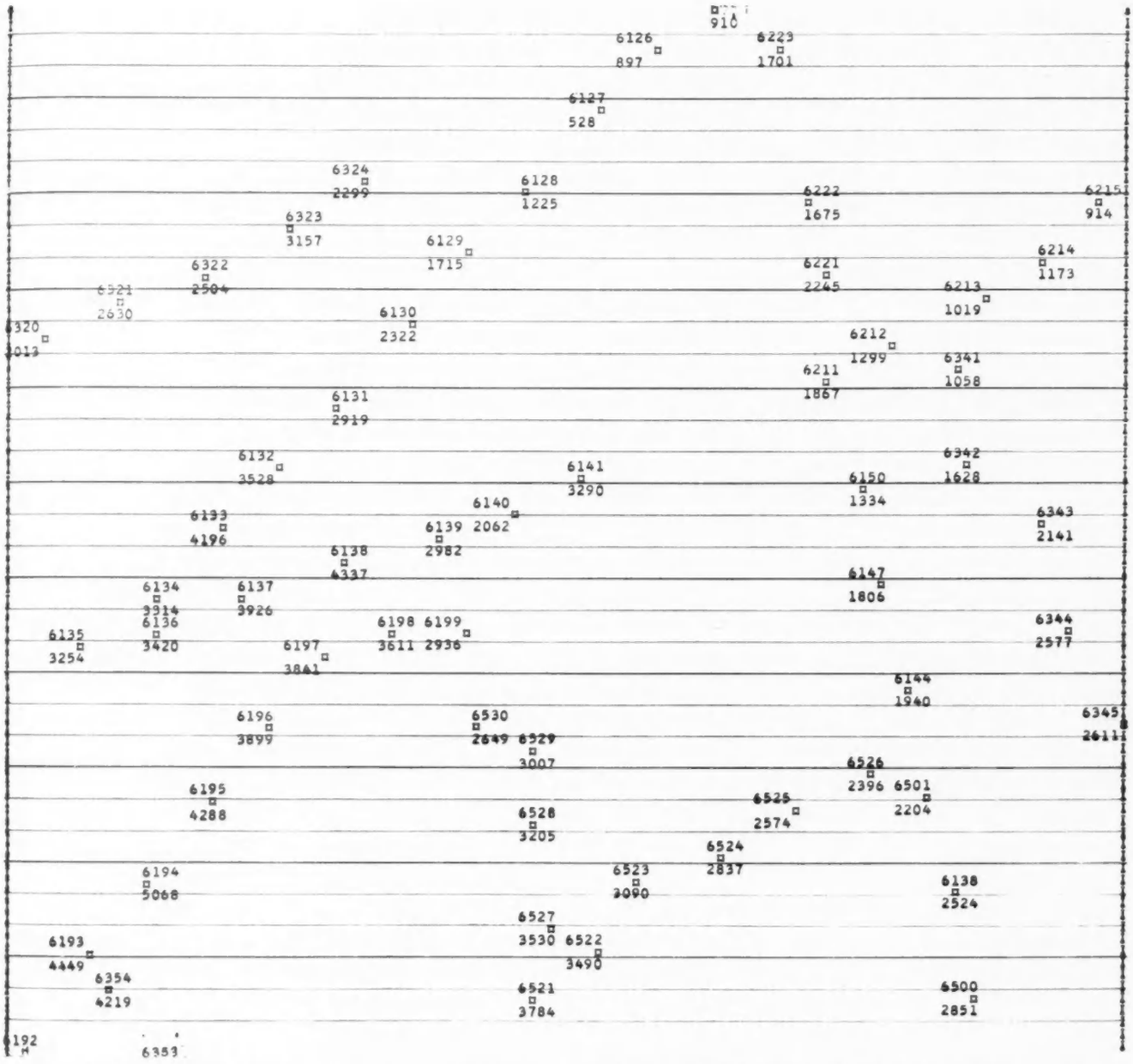


FIGURE 2—This shows a portion of a seismic map which may be plotted by electronic computers. The map may be plotted for any indicated horizons, including phantoms. Depending on availability of velocity data, depth maps may be plotted using a single velocity function, a velocity gradient, or a velocity surface.

tractive. Electronic computers are being used as an aid to interpretation in both cases.

Qualitative analysis. To define the beds and detect repeated or omitted intervals of the geologic section the log must be correlated with one or more logs in the same area. Quite often several intervals are found with seemingly the same magnitudes of similarity. Or perhaps the interpreter cannot survey the over-all characteristics of a large interval where individual small members may be erratic. In these cases it is often helpful to have a statistical measure of the similarity of two intervals. This helps the interpreter to know whether or not a correlation exists.

Statistical correlation of electric logs. The machine process is very similar to the manual method. Two logs are placed side by side (or the two digitized logs are stored in the computer) and one is displaced by separate steps. A correlation is computed for each step. The computation is simply the multiplication of the corresponding amplitudes of the curves and the summing of them for each step (Z). The maximum correlation value or values is the point at which the correlation is most likely (Figure 1).

This process requires many thousands of multiplications and additions on the computer and could consume much machine time if an unwise choice of a starting point is made. Correlation intervals should be chosen as narrowly as possible without sacrificing any distinctive log characteristics which might be correlatable. The best use of this routine is in sections where there are too many correlatable log characteristics for the eye to separate.

Quantitative analysis. Detailed analysis of carefully-chosen electrical and radioactivity logs provides a method of obtaining values for saturation and porosity, and indications of

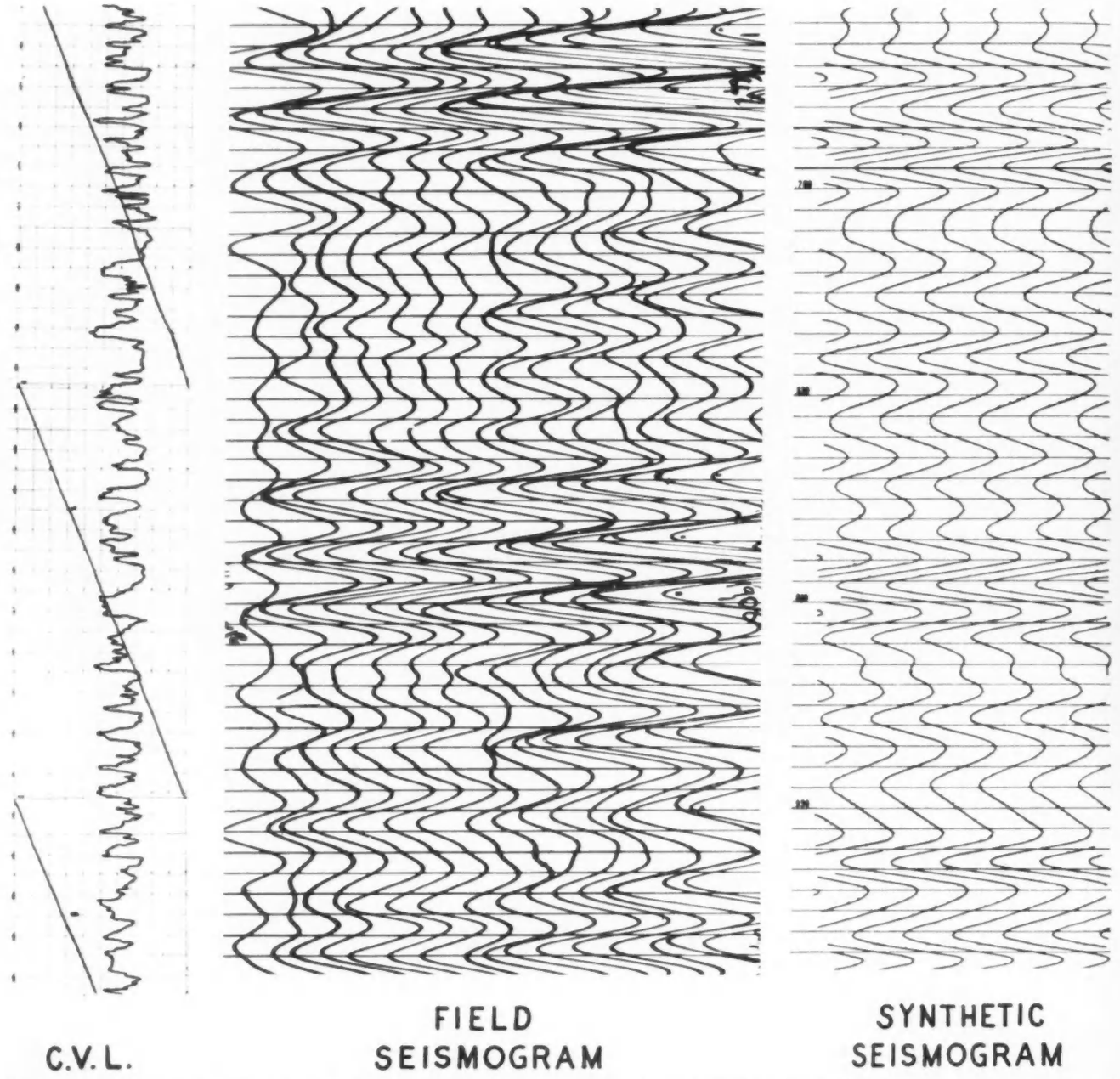


FIGURE 3—If a continuous interval velocity log (CVL) is available, a synthetic seismogram may be constructed on a computer and plotted for comparison with the field seismogram. This identifies the origin of reflections and any multiple arrivals on the field seismogram.

permeability. Several logging companies have published theoretically and empirically determined equations and charts which relate borehole parameters. Use of proper combinations of these relationships yield values for the quantities desired. Use of a stored computer program alleviates the laborious and often error-conducive aspects of this process.

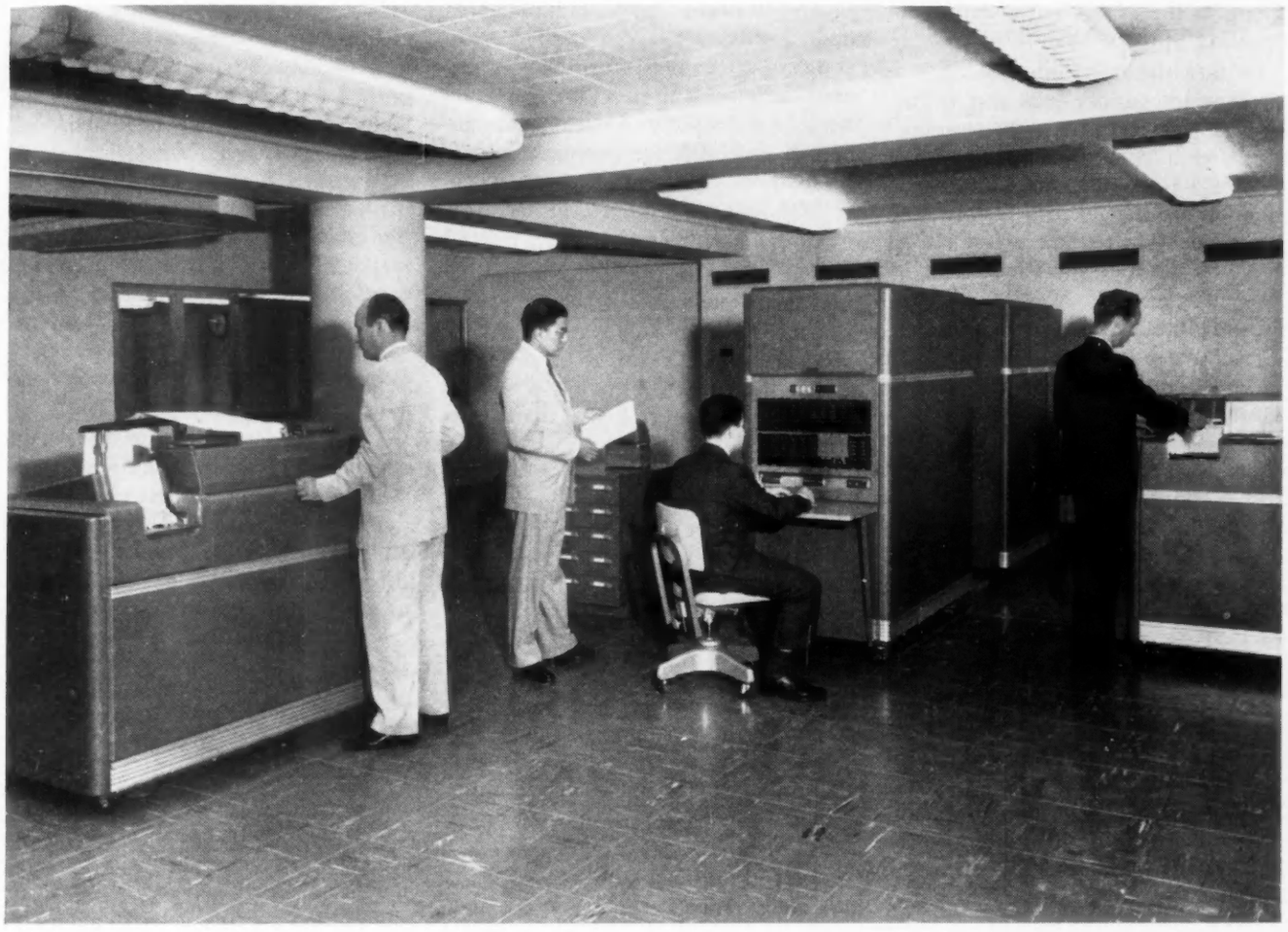
Generally, the stored program includes the charts and curves in the form of tables or equations. The data obtained from the logs are entered on cards; then the machine scans the tables, makes computations and decisions to arrive at the values. Whenever insufficient information is fed into the machine, it signals that a final result cannot be reached with the data; henceforth, the proper correction can be made.

The advantages of machine interpretation over the manual method may be summarized as follows:

- A standard may be set for interpretations of logs in almost any area. More important, this standard can be modified for peculiar effects in each area, thereby allowing for integration of *experience* into the program based on production data. *Loss of experienced personnel need not mean the loss of experience.*
- Human error in the interpretational process is minimized
- Historical files may be processed in search for overlooked potential reservoirs and workover possibilities with minimum personnel and time
- Logging and interpretational procedures may be evaluated to see if best information is gained for the investment
- Evaluation of reservoirs is rapid, approximately 100 sands per hour

STATISTICAL EXPLORATION

Many basins have sedimentary sections composed of numerous, irregu-



Automatic data-processing, plotting and electronic computing equipment in use along same lines as methods described in text.

larly-shaped lenticular sands which are hydrocarbon reservoirs when interbedded with shale. These areas seem to be devoid of structural trapping possibilities due to the limits of resolution of geophysical and geological techniques. Most stratigraphic production from such areas has generally been associated with structural reservoirs, since geophysical techniques are more effective in detecting structures. Minor faulting may be similarly undetected.

A question arises as to how many of these nondetectable traps exist on a specified "large" lease or concession and how much oil can be expected to be present. The true answer is obviously a statistical one. A good estimate can be given if sufficient pertinent information is available. For the economists or management the question might be rephrased to read, "How much profit can we expect from this property in view of exploration and production costs?" or (more simply), "what is the value of this property and how much can be spent in advance on exploration and still yield an attractive rate of return on the investment?" Of course, associated chance factors such as unfavorable market conditions, political conditions, competitor activity and concession or lease termination deadlines affect the answer and must be considered in some way.

To evaluate the property properly, concern must be shown for all factors which significantly affect the accumulation, production and the cost of exploring and developing reserves. These factors naturally include the *size, shape, orientation* and *distribution* of the potential reservoirs. Other pertinent factors include costs of leases, costs of exploratory drilling and geophysical surveys, and the rates of return from developed reservoirs.

The procedure assumes that an area can be proven by grid or pattern drilling. The problem is then to determine the grid spacing, orientation of lines and how these parameters can be varied to take advantage of local conditions (e.g., abnormal land costs, locally known geological conditions). To find values for these parameters the available statistics must first be summarized in the form of distribution functions to render them applicable. For example (Figure 1-A) the complete set of reservoirs is classified as to the horizontal area against the frequency of occurrence of each size.

Based upon the frequency area distribution (Figure 1-A), the frequency-shape distribution (Figure 1-B), and the shape-area distribution (Figure 1-C) along with volume considerations, it would be possible to specify a grid spacing which would include a specified percentage of the reservoirs. This would undoubtedly be uneconomical since, among other considerations, it neglects all cost requirements.

If consideration is given to the frequency-orientation distribution (Figure 1-D) and the frequency (potential reservoir sands per well) distribution (Figure 1-E) then the grid-spacing and orientation of the lines are specified for any desired percentage of successes. However, this is still insuf-

ficient, as the evaluation should be in monetary units to have meaning.

To find the optimum spacing it is necessary to consider lease and drilling costs (Figure 1-F) and the expected rate of return on any size reservoir (Figure 1-G). This allows the determination of the correct pattern and number of wells for maximum rate of return on the total investment.

More refined geological, geophysical and any other information is then admitted to the problem in order to detect any significant effects it may have on the solution. The usual effect will be to *destroy* the grid pattern and yield optimum locations to drill.

Although the stated factors are some of the most important in the general problem, there will naturally be many variations in stating the problem, requiring consideration of other distributions.

Hence, the computer's role is to summarize the voluminous data necessary in the preparation of distribution functions. Should assumptions be made as to the nature of smoothed-out distributions, then the computer will fit the desired function to the data and compute the most satisfactory values of the parameters of the functions.

GEOPHYSICAL APPLICATION

Reflection seismic data. Since most of the interpreter's time is devoted to the routine reduction and handling of data on the average seismic survey, insufficient time remains to extract more information and to utilize trial and error methods. Most of these tasks require standard calculations and decisions which are ideal automation criteria.

TABLE 1—Time-depth chart for determining the equation which best represents the time-depth data. Equations are then admitted to the computer which effects a depth isopach map for each desired horizons.

$V = V_o + aZ$

$V_o = 6455$ $a = 663$

Time	Depth	Time	Depth	Time	Depth
1500	6272	1600	6811	1700	7369
1501	6277	1601	6817	1701	7375
1502	6282	1602	6822	1702	7380
1503	6288	1603	6828	1703	7386
1504	6293	1604	6833	1704	7392
1505	6298	1605	6839	1705	7397
1506	6304	1606	6844	1706	7403
1507	6309	1607	6850	1707	7409
1508	6314	1608	6855	1708	7414
1509	6319	1609	6861	1709	7420
1510	6325	1610	6866	1710	7426
1511	6330	1611	6872	1711	7431
1512	6335	1612	6877	1712	7437

Hence, many steps in a reflection data gathering and interpretation project may be performed by computers. Various such steps are discussed here. If the input and output data are chosen carefully, these programs may be used in sequence with a minimum of card punching.

Survey network. Errors which enter seismic surveying data due to human and instrument inaccuracies must be smoothed or adjusted out to tie with control points. Error distribution is accomplished on the computer so that the network conforms to as many control points as desired. The computation technique is a form of relaxation method which computes the corrected coordinates for each shot point and punches out a deck of cards with this information, as well as the elevations of each point.

A base map may be plotted, to any scale, by the use of a special plotting control panel in the plotter. An elevation map may also be plotted, if desired. The plotting proceeds at a maximum of 150 points per minute.

Analysis of raw reflection data. There has been no practical method developed to pick and record automatically reflection information needed for interpretation. Therefore, manually picked "raw" reflection times along with datum velocity information must be recorded on the coordinate card from the survey. With the furnished information the computer will compute the corrections needed to reduce the reflection times to a specified datum.

Should a cross-section (time) be desired, then it will be plotted to scale on the plotter. If velocity information is available, a depth section can be plotted also. In case of steep dip in the area it is often necessary to migrate the reflections back to original positions in depth or time, resulting in a plotted migrated section.

After the selection of mapable horizons and faults (if present) from the cross-sections, then map construction may begin (Figure 2). Maps are plotted for any or all of the horizons, including phantoms (in which case dips are averaged). Again, if velocity information is available, a depth map is plotted using a *single velocity function*, a *velocity gradient* or a *velocity surface*. Naturally, isopachs are developed in much the same manner as the other maps. The same basic deck of cards is used for all of these operations with any new information being added at any time.

Velocity determination for depth conversion and migration. Time-depth information obtained from detonating dynamite charges near the surface and recording the time of arrival of the sound wave at geophone positions in a well is probably the best velocity information available for the conversion of reflection time data to depth. However, to apply this information to the large amounts of data it must be expressed in an analytic equation (Table 1). This is accomplished by a curve fitting routine which finds the low order polynomial or equation which best represents the time-depth data. The ascertained equations are then admitted to the computer to effect a depth isopach map for each of the desired horizons.

Migration charts or templates (for map 3-dimension migration) are computed from the time-depth equation to be applied to time maps (Table 2).

In many areas of exploration there is either no, or insufficient, well velocity information. In these cases it is often feasible to use surface methods to determine interval velocities and an over-all velocity function. Refraction lines will yield usable velocity information if properly treated.

Tying mapped horizons to geologic horizons in available wells (Figure 3). In order to transform each seismic

TABLE 2—Ray Trajectory Migration—Linear Increase in Velocity With Depth.

Z is Depth. **H** is Horizontal Offset.

TIME	2.000		2.010		2.020		2.030		2.040		2.050	
△T	Z	H	Z	H	Z	H	Z	H	Z	H	Z	H
0	9503	00	9569	00	9635	00	9702	00	9769	000	9836	000
2	9502	69	9568	69	9634	70	9701	71	9768	71	9835	72
4	9501	138	9567	139	9633	138	9700	142	9767	143	9834	144
6	9499	207	9565	209	9631	211	9698	213	9765	215	9832	217
8	9497	276	9563	278	9629	281	9696	284	9763	286	9830	289
10	9494	345	9560	348	9626	351	9693	355	9760	358	9827	361
12	9490	414	9556	418	9622	422	9689	425	9756	429	9823	433
40	9369	1372	9433	1384	9497	1397	9563	1410	9628	1423	9693	1436

depth map to one with geologic meaning, the mapped horizon must be tied in with available well control. If a continuous interval velocity log (CVL) is available in the well, a synthetic seismogram may be constructed on the computer and plotted so that a comparison can be made with the field seismogram. This identifies the origin of the reflections and any multiple arrivals present on the field seismogram.

If several wells are present in the area to serve as control depth points for the mapped horizon, then the error existing between them and the seismic depth map may be entered on cards, and the complete map will be adjusted to agree with the control. Here again the corrected map is plotted out.

Stratigraphic analysis. With the recent shift of emphasis toward stratigraphic analysis using the reflection seismograph, several tools have been developed to this end. One of the most frequently used to find pinchouts of potential sands is the synthetic seismogram. The general procedure is to construct a synthetic seismogram from a CVL and correlate it with a field seismogram to determine the effect and position of a specified bed on the seismogram. The bed is either thickened, thinned or eliminated from the CVL and a new synthetic seismogram is computed from the modified CVL. The effect of this modification is observed, and an analogous event is searched for on the neighboring field seismograms. This act is repeated until a plausible solution is found.

Another tool being used to detect pinchouts is a process of mathematical filtering of the field seismograms. This technique is used to eliminate or exaggerate certain bands of frequencies without introducing electronic distortion. An example of this follows. If a reflection interval is believed to be responsive to a 60-cycle pulse, then a mathematical filter is designed to emphasize or eliminate this frequency from the reflection on the seismic record. The results are analyzed to yield a measure of the responsiveness of this interval to the 60-cycle pulse and, therefore, a measure of the interval thickness. The filtered seismogram is plotted out in the same manner as the synthetic.

Statistical prediction of the presence or absence of a reflection in a certain interval on a reflection seismogram is being used in a limited way for stratigraphic analysis. The prediction is based on previous amplitude values of the seismic traces to predict the probability of amplitudes in the specified interval. Therefore, a probability of the absence or presence of a reflection in the interval is obtained.

Gravity data interpretation. Here the interpreter's time is devoted more to routine calculations and corrections than in the case of reflection seismic interpretation. Standard procedures and equations are usually adopted by gravity interpreters so that basic interpretation differences result from differences in such basic assumptions as near-surface densities and grid spacings. The computer's calculation speed and versatility in plotting maps allow many studies of parameter variation.

A generalized interpretation procedure is presented below in order to demonstrate the steps in which use of a computer would be advantageous. Many of the routines discussed in the seismic interpretation section are used here also.

Survey network. Adjustment of the network survey is the same procedure as described under seismic. Observed gravity values may be plotted in map form as well as the base (station coordinate) and station elevation map.

Regional and residual separation. A reliable study of either regional, or residual gravity requires separation of their effects. The usual approach is to assume that basement gravity values change slowly compared to the overlying sedimentary anomolies. Consequently (allowing for a faulted basement), regional gravity may be approximated by a low-order surface, but higher order than a plane. The "least squares" surface-fitting routine for regular or irregulary spaced points is used to accomplish the separation.

Regional and residual values may be plotted out on one or two maps for contouring. At present several geophysical laboratories are experimenting with approaches to contouring regional maps automatically.

Interpolation of gravity values at grid points for irregularly spaced stations. Prior to the computation of a second derivative map or any analysis of residual values, gravity values must be determined at either square or triangular grid points. Again a "least squares" curve-fitting routine is used to interpolate the station values.

Following the grid map construction the size of the averaging circles is decided upon for determination of a second derivative map. The size of circles need not remain constant over the whole map but may be varied according to the size and configuration of the local gravity anomaly.

Shape, depth and center of gravity. Determination of computation of the shape, depth and in some cases the center of gravity is being attempted on digital computers. However, the computation of either of these parameters is based on assumptions of the characteristics of the others. Therefore, the best that can be hoped for is the comparison of the assumptions against variation of the assumptions.

(This article is based on a paper presented at the Mid-Continent Regional Meeting of The American Association of Petroleum Geologists in Wichita, Kansas, Oct. 27-30, 1959.)

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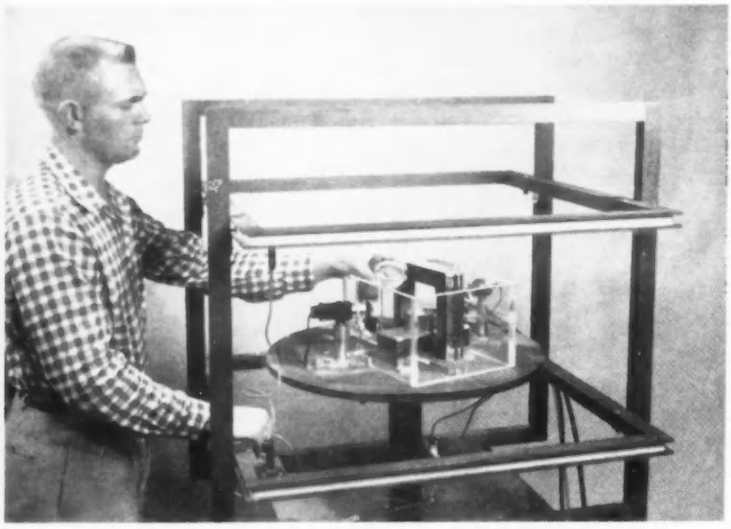
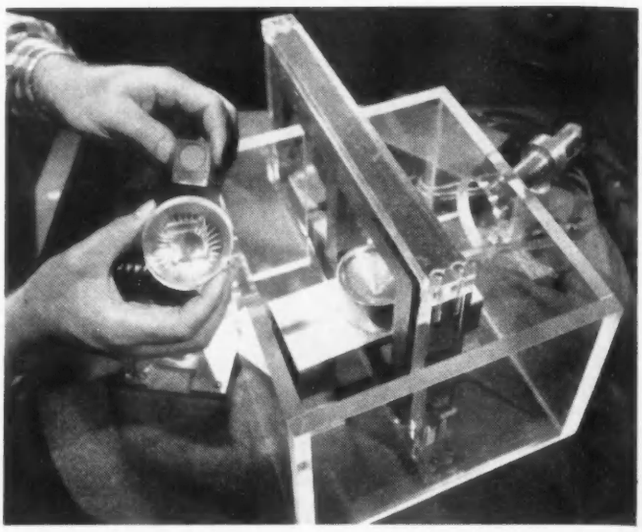
About the Author

Edward J. Assiter is a petroleum representative in Venezuela for International Business Machines Corporation. He holds B.S. and M.S. degrees from the University of Oklahoma, where he majored in mathematics with an additional major in geology with geophysical option. He worked four years for Socony Mobil de Venezuela as senior seismic interpreter, and was engaged in developing the Exploration Department's electronic computer group during two of his years with Socony. Assiter is a member of the Society of Exploration Geophysicists and of the Venezuelan Association of Geophysics.



Arley Walters, laboratory technician, Shell Development Company, places plastic spinner containing core sample inside magnetic field of the laboratory magnetometer. The sample is processed three times, once in position parallel to its axis and once each in the two directions perpendicular to its axis.



Closeup (right) shows cylindrical sandstone core plug in square holder ready for emplacement in the spinner, which in turn is placed in the magnetometer.

Magnetic orientation of cores aids oil search

Configuration of sandstone lenses, trends of regional sand bodies detectable in subsurface

CONSIDERABLE PROGRESS in the quest for stratigraphic traps and favorable sand trends is being made through magnetic orientation of sandstone cores. This research is providing Royal Dutch Shell Group companies with an additional tool for guiding field development and exploratory trends.

This research is being done mainly at Shell Development Company's Exploration and Production Research Division laboratories in Houston. The program to study orientation of sand grains began almost 10 years ago, when Shell geologists removed naturally-compacted sand from Galveston beach, after noting the compass orien-

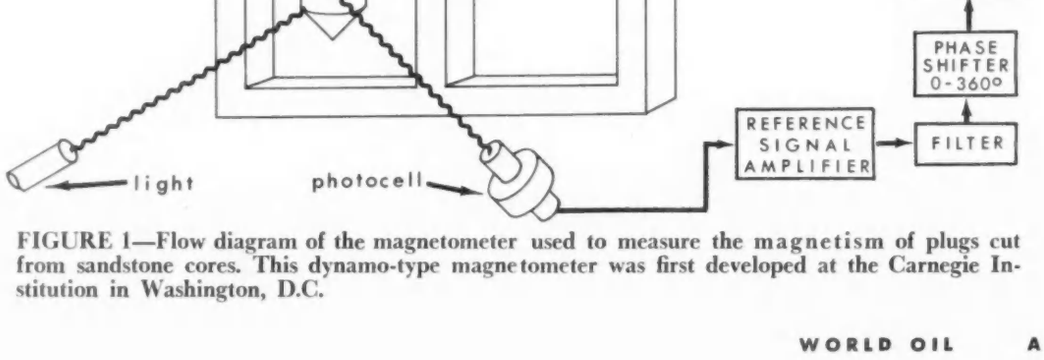


FIGURE 1—Flow diagram of the magnetometer used to measure the magnetism of plugs cut from sandstone cores. This dynamo-type magnetometer was first developed at the Carnegie Institution in Washington, D.C.

tation of each sample. Microscopic study confirmed that the long axes of most of the sand grains are oriented parallel to the depositing currents, in this case parallel to the direction of incoming waves. With this general rule established, Shell proceeded to determine the orientation of long axes of sand grains in older sandstones.

Magnetic material deposited with sandstones becomes oriented in accordance with magnetic north direction at the time of deposition. Provided that the sandstone is compacted sufficiently, and secondary factors such as ground water do not alter them later, iron-bearing minerals retain their magnetic orientation.

Of course, if magnetite is present, it provides a stronger magnetic effect than any other clastic material. However, it is not essential that magnetite be present, since other iron oxide and iron-titanium oxide minerals are also magnetic, although more weakly so.

In order to make magnetic orientation of cores meaningful, Shell conducted a program to determine from the magnetic direction in outcrop samples the position of the north magnetic pole during the post-Cambrian geologic past. Shell's findings in general corroborate those recorded in the literature. The position of the magnetic pole has been relatively stable since Eocene time. At the close of the Paleozoic, it was located in southern Argentina. Paleozoic magnetic polar relationships are still being worked out.

Processing cores. In preparing cores for processing, cylindrical-shaped plugs about an inch long and ¾-inch in diameter are drilled from a core sample. As many as five plugs per sample are thus extracted and analyzed in the magnetometer. A drill press with a diamond bit is used to cut plugs.

The magnetometer used to measure the magnetism in the plugs is the dynamo type first developed at the Carnegie Institution in Washington, D.C. Each plug is processed in the magnetometer three times, once parallel to its axis, and once each on the other two directions perpendicular to its axis. The plug is placed in a plastic holder which in turn fits into a plastic spinner. The spinner is then placed in the magnetometer, which consists essentially of a pick-up coil with attendant electronic equipment to conduct, amplify, filter, and record the minute current induced when the magnetic field produced by the magnetic material in the sample is rotated at high speeds (19,800 rpm) within the coil.

. . . orientation of sand grains now being deposited, and of post-Paleozoic magnetic north, determined in field . . .

A very minute signal, usually in the order of a millionth of a volt, is induced, amplified, filtered, and recorded as an azimuth related to the *fixed position of a reference current* (see flow chart, Figure 1, and diagram showing typical results from a plug run through the magnetometer operation routine, Figure 2). Under ideal circumstances, the three arcs plotted from the results from each plug will intersect at the same point, which indicates the orientation of the plug, and of the core. More often the arcs will describe a triangle of error, the center of which is the approximate magnetic direction and gives the orientation of the core.

Shell's experience indicates that this work has valuable practical applications. The ability to predict the direction of sand deposition from cores is very helpful in field development, particularly in lenticular sandstones and other stratigraphic traps.

Limitations. At this time, the magnetic properties in some rocks are not favorable for core orientation. The magnetism may be too weak to measure; or it may be unstable or have been altered for a variety of reasons which are incompletely understood. In addition, the wanderings and vagaries of the north magnetic pole during the Paleozoic Era are not completely known, and these uncertainties make orientation of Paleozoic cores less certain. **—The End**

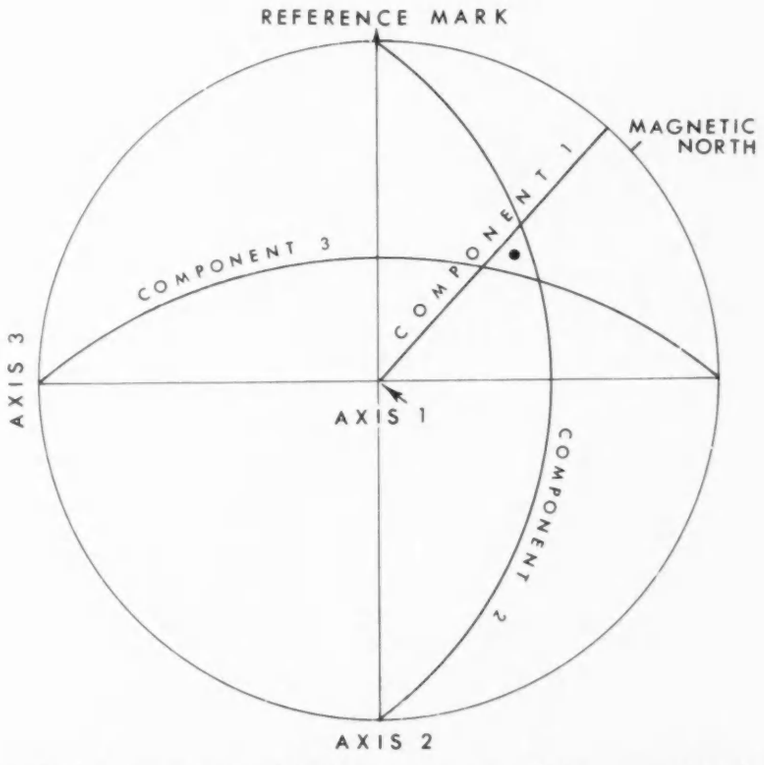


FIGURE 2—Each plug drilled from a core sample is processed in the magnetometer three times, once parallel to its axis, and once each in the other two directions perpendicular to its axis. Under ideal circumstances, the three arcs plotted from the results from each plug will intersect at the same point, which indicates the orientation of the plug and of the core. More often the arcs will describe a trinagle of error (as shown here), the center of which is the approximate magnetic direction and gives the orientation of the core.

How to do refraction work by remote control

Proper instrumentation solves communication problems and other former handicaps

By Pascal Vetterlein, Senior Research Engineer
PRAKLA, Hannover, West Germany

A NEW remotely controlled refraction seismograph system has been developed and used in the field, simultaneously providing advantages of joint registration, methods simplification, and reduction of operating personnel. The system is especially useful to evaluate large, remote areas. In addition, a special application of this remote control system is found in offshore operations. The receiving station can be installed in a fixed buoy.

Refraction surveys are still frequently used because they provide a quick reconnaissance of an area to be investigated. Linear geophone spreads are preferred. However, the so-called fan procedure, in which the seismometers are located fan-wise around the shotpoint, is often employed.

Conventional refraction methods have in common that one single shot cannot be recorded by the entire refraction line, but a number of individual shots must be detonated in sequence in the same shothole or in adjacent shotholes while the geophone spread is moved to another section of ground. Since a 30-mile refraction line is not unusual and the length of a single spread can hardly exceed a half mile, 60 individual shots are required to record the refraction line in one direction.

Theoretically, several half-mile lines might be laid simultaneously and connected by wires to acquire a general oscillogram from one shot. Aside from inherent difficulties of maintaining such long connections, the recording quality and clarity of seismograms decrease if line losses between geophone and amplifier exceed a certain rate. Also, shots exploding successively in the same shothole (or adjacent shotholes) never radiate the same amount of energy. This impairs seismic interpretation.

Hence, it would be highly advantageous to record a refraction line, whether as a line or area investigation, simultaneously with one shot. The unchanged geophone layout

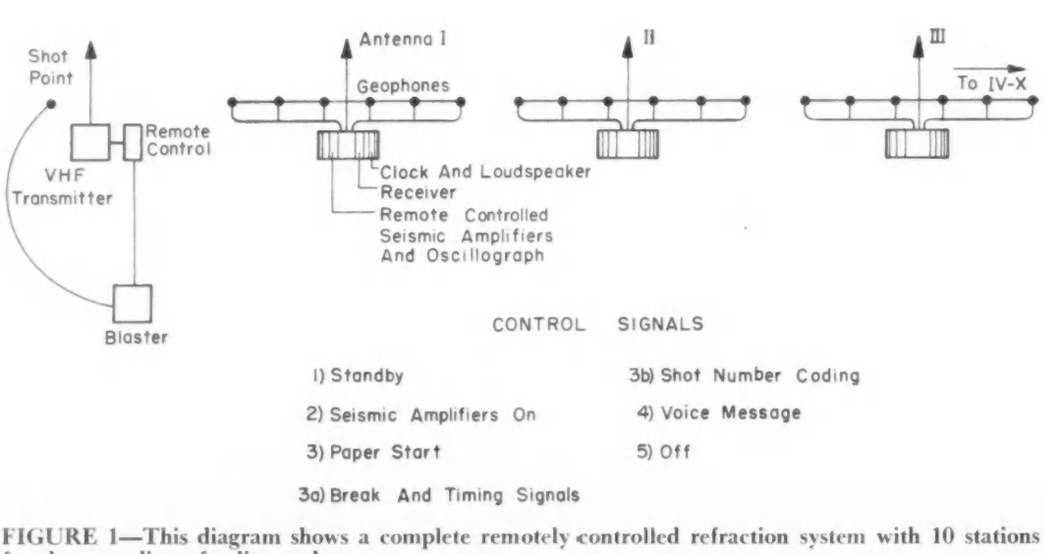


FIGURE 1—This diagram shows a complete remotely controlled refraction system with 10 stations for the recording of a linear shot.

would prove advantageous for counter shooting, for which only one shot would be required also.

In the aforementioned offshore application, the receiving station can be installed in a fixed buoy and, similar to conventional reflection shooting, refraction can be recorded by controlling the receiver from the shooting vessel. A high-capacity oscillograph spool allows as many as 40 recordings without changing the paper.

How it works. In the new method, single layouts of the geophone groups are completely independent. For example, for a line of six channels, a cable of about half a mile will be laid. The geophones are connected, and amplifiers and oscillographs are wired with the cable. These spreads correspond to conventional methods. However, adjustment and release of the instruments are not performed by an operating technician, but occur fully automatically, i.e., remotely controlled by a transmitter located near the shotpoint. Any number of receiver stations may be combined and each shot is simultaneously recorded by many receiving stations. Different methods of transmission and receiving are explained in detail as follows.

A VHF transmitter is placed near the shotpoint. This transmitter can be modulated by different audio-frequency voltages as well as by a built-in crystal-controlled time scale. The modulating unit is operated by a technician who communicates with the shooter via a standard-type call-wire. These instruments are powered by batteries and are readily portable.

Near each geophone spread, a VHF receiver is placed, together with an operating part for six seismic amplifiers, an oscillograph, and some generator parts. All of this equipment is installed in a readily portable box. A lightweight storage battery serves as energy source. As many as 10 such receiver stations may be placed in a light field vehicle. Only one trained helper is required for the transport and layout of stations, which are all moved in the same vehicle; and only one field helper is required to observe the system. A routine system of checks of cable arrangement and geophone spreads has been worked out.

Much development work was done to assure that all functions, e.g., adjustment of amplifiers, runoff of seismogram paper, etc. proceed fully automatically and require no readjustment. Sensitivities of single amplifiers are first adjusted by hand to a certain scale. Thru use of a slowly-running control circuit, automatic gain control (AGC) may be acquired. AGC enables the noise signal to produce a barely legible seismogram registration prior to the shot, so that the amplifier can be fully utilized for the anticipated information signal.

All spurious effects which would impair the measuring process have been essentially eliminated. Each of five control functions is fed with a different (audio-frequency) voltage. Frequencies are so selected that effects of overtones and different frequencies are avoided.

FIGURE 2—This photo shows the control element of the VHF transmitter with operating keys for different switching functions, indicator lights, chronometer, and identification impulse transmitter.

Switching functions are described as follows (Figure 1):

1. Device to keep the receiver-relay "on"
2. Seismic amplifiers "on"
3. Start oscillograph motor
   a. time signal
   b. shot number coding
4. Voice message—announcement to helpers by telephone transmitter
5. Switching off

1. Receiver-relay on. Thru use of a clockwork mechanism all receivers are connected during certain two-minute intervals, e.g., every half hour. Upon receipt of the "put on receiver-relays" (signal 1), the receiver can remain connected automatically beyond the two minutes without need for another signal. In

FIGURE 3—This is a receiver station with receiving element, antenna, cable, and other functional equipment. Ready portability of the equipment is evident.

case of any incident, the receiver can be switched off (signal 5), and may be re-connected after the next interval. The system conserves energy, and operating readiness is maintained all day long.

2. Seismic amplifiers on. Seismic amplifiers are connected at a specified time before detonation of the shot. Owing to special connection of amplifiers independent of receiver-relay switching (signal 1), current consumption and unnecessary usage are lessened.

3. Start oscillograph motor. Detonation of the shot is accompanied by an audio-frequency wave to start the oscillograph motor; this signal is simultaneously transformed into crystal-controlled impulses at 20 millisecond intervals. Every fifth impulse (i.e., at 100 millisecond intervals) will be somewhat less intense. The start-oscillograph (signal 3) and time (3b) signals are recorded on oscillograph loops at the margin of the paper tape. This method assures that shotbreaks and time marking are uniformly represented on oscillographs.

The time signal can again be switched over via manual operation to the sound-frequency signal 3. A contact controllable from a telephone dial supplies the start-oscillograph signal with marking impulses at short intervals, providing uniform coding of the shot number for all receiver stations.

4. Telephone message to helpers. Whenever no additional sound signal is given, a microphone may be switched on to provide oral communication with field personnel. A primary use of this is disassembly of instruments following the shot.

5. Switch off. Receivers and holding relays are disconnected and the whole system is taken out of circuit. To prevent this signal from being released by mistake, it is specially locked, and started with two separate keys.

All remote control functions are released with a certain time delay, to avoid false starts owing to interference impulses. Experience shows that even relatively strong interference voltages cannot impair the system's safety.

Each station may be manually operated instead of radio-controlled. The receiver is built as a replaceable inset. A different inset containing a push-button system and a time signal sender may be installed. Portability of all equipment is apparent from Figures 2 and 3.

The new remotely controlled refraction system thus provides quick coverage of a large area with a minimum of personnel. Recording of many seismograms from one shot, and constant shot conditions resulting therefrom are of special importance.

—The End

About the Author

Dr. Pascal Vetterlein has worked for Gesellschaft fur Praktische Lagerstattenforschung GmbH (PRAKLA) since 1954, specializing in high-frequency seismic techniques and attendant magnetic tape recording, and marine seismic operations. He was born in the Rhineland at Darmstadt in 1910. He studied physics at the Technical College at Hannover, where he received his first engineering degree in 1936 and his doctorate in 1939 with a thesis on spectrum analysis and gas flow. Vetterlein is a member of the European Association of Exploration Geophysicists and the Society of Exploration Geophysicists.

How high are Free World oil search, development costs?

About $38.5 billion spent in United States, $13.8 billion elsewhere during 1949-1958

(Based on data published by the Petroleum Department, The Chase Manhattan Bank)

RECENT STUDIES have yielded important compilations of expenditures for exploration and production facilities in the Free World. Some of the pertinent conclusions are as follows:

- During the decade 1949-1958, $38.5 billion was spent for finding and expanding crude oil and natural gas production in the United States. Geological and geophysical work and lease rentals amounted to $5.4 billion or 14 percent of the total
- More than $13.8 billion was spent in these efforts in the Free World outside the U.S. during the 1949-1958 period. About 16 percent of the $13.8 billion spent for finding and developing oil and gas abroad was for geological and geophysical work and concession costs
- Non-capitalized expenditures for geological and geophysical work and lease rentals in the U.S. thus amounted to $5.4 billion during the 1949-1958 period, and to $2.2 billion in other Free World countries
- Expenditures for maintaining and expanding crude oil production in the United States increased from $1.58 per barrel produced in 1952 to $1.95 per barrel produced in 1957. U.S. return on investment in production, based on existent crude oil and natural gas prices, replacement and lifting costs declined rapidly from 1947 to 1957
- There is a longer lag period between exploration and production phases in areas outside the United States than within.

During the 10-year period 1949-1958, expenditures for replacement and expansion of property, plant and equipment by the Free World petroleum industry totaled $78 billion, of which $48 billion or 61 percent was invested in the U. S. This outlay is shown by years and areas in Table 1, by departments in Table 2, and by areas in Table 3.

TABLE 1—Free World petroleum industry expenditures, 1949-1958, for replacement and expansion of property, plant, and equipment, in and outside the U.S.

Year	Million Dollars			Percent of Free World	
	United States	Other Countries	Free World	United States	Other Countries
1949	3,000	1,925	4,925	60.9	39.1
1950	2,925	1,500	4,425	66.1	33.9
1951	3,625	1,700	5,325	68.1	31.9
1952	4,400	2,350	6,750	65.2	34.8
1953	5,025	2,550	7,575	66.3	33.7
1954	5,350	2,725	8,075	66.3	33.7
1955	5,600	2,950	8,550	65.5	34.5
1956	6,050	3,975	10,025	60.3	39.7
1957	6,400	5,000	11,400	56.1	43.9
1958	5,300	5,400	10,700	49.5	50.5
Total	47,675	30,075	77,750	61.3	38.7

U.S. Share of World Capital Outlays Continues to Decline

Ten-year comparisons of investment and cost figures reveal the following trends:

- For the first time in its history, the United States accounted for less than half (49.5 percent) of the Free World's expenditures for finding and developing petroleum reserves in 1958. The U.S. share has been declining steadily since reaching a peak of 68.1 percent in 1951.
- Even so, capital investments in the United States have remained relatively stable, reaching a peak of $6.4 billion in 1957.
- Although 1958 capital outlays to find and develop oil and gas reserves in the United States were nearly double the 1949 total, this country's share of the world total dropped from 71.8 to 64.5 percent.
- Of five major oil and gas areas, only the United States has reported a major increase in per-barrel cost of maintaining and expanding crude oil production during the past decade. The U.S. per-unit cost in 1958 was $1.73 per barrel, up 53 cents per barrel or 44.4 percent over 1949.
- In contrast, Canada's per-barrel costs dropped $4.39 per barrel or 63.7 percent, to $2.51 per barrel in 1958. Venezuela's costs averaged 58 cents per barrel in 1958, down 18 cents or 23.7 percent from 1949.
- During the same ten-year period, Middle East costs declined 12 cents per barrel or 36.4 percent, to 21 cents per barrel, while Far East costs declined 28 cents per barrel or 24.1 percent, to 88 cents per barrel.

TABLE 2—Free World petroleum industry expenditures, 1949-1958, for replacement and expansion of property, plant and equipment, by departments.

Department	Million Dollars			Percent of Total	
	United States	Other Countries	Free World	United States	Other Countries
Production	34,025	11,510	45,535	71.3	38.3
Pipe Lines	2,425	1,615	4,040	5.1	5.4
Tankers & Other Marine Equipment	605	5,495	6,100	1.3	18.3
Refineries	5,400	5,940	11,340	11.3	19.7
Chemical Plants	900	335	1,235	1.9	1.1
Marketing	3,470	4,435	7,905	7.3	14.7
Others	850	745	1,595	1.8	2.5
Total	47,675	30,075	77,750	100.0	100.0

TABLE 3—Free World petroleum industry expenditures, 1949-1958, for replacement and expansion of property, plant, and equipment, by areas.

Area	Million Dollars	Percent of Total
United States	47,675	61.3
Canada	4,700	6.1
Venezuela	4,774	6.1
Other Countries	2,795	3.6
Western Hemisphere	**59,944**	**77.1**
Europe	5,730	7.4
Africa	1,250	1.6
Middle East	2,810	3.6
Far East	2,576	3.3
Eastern Hemisphere	**12,366**	**15.9**
Unallocated (incl. Foreign Flag Tankers)	5,440	7.0
Total	77,750	100.0

Figures in Tables 1, 2, and 3 include the cost of drilling dry holes and lease-concession acquisitions, but *exclude* geological and geophysical expenses and lease rentals amounting to $5.4 billion in the United States and $2.2 billion in other countries for the years 1949-1958.

Cost of expanding crude production. The petroleum industry requires substantial funds for finding and developing crude oil and natural gas reserves. These expenditures by the Free World petroleum industry during the years 1949-1958 totaled $52 billion of which 74 percent was spent in the United States and 26 percent abroad, as summarized in Table 4.

TABLE 4—Expenditures, 1949-1958, for expanding crude oil and natural gas production and reserves in the Free World.

Year	Million Dollars			Percent of Free World	
	United States	Other Countries	Free World	United States	Other Countries
1949	2,215	870	3,085	71.8	28.2
1950	2,325	600	2,925	79.5	20.5
1951	2,975	725	3,700	80.4	19.6
1952	3,625	1,065	4,690	77.3	22.7
1953	3,975	1,065	5,040	78.9	21.1
1954	4,300	1,170	5,470	78.6	21.4
1955	4,675	1,360	6,035	77.5	22.5
1956	5,075	2,025	7,100	71.5	28.5
1957	5,100	2,555	7,655	66.6	33.4
1958	4,225	2,325	6,550	64.5	35.5
Total	38,490*	13,760	52,250	73.7	26.3

* Excludes expenditures for gasoline and cycling plants totaling $910 million

The combined figure of $52 billion (Table 4) *includes* the cost of drilling dry holes and lease-concession acquisitions, geological and geophysical work and lease rentals. Expenditures for the latter two items represent 14 percent of the total cost in the United States and 16 percent abroad.

Distribution of this outlay by areas outside the United States is shown in Table 5.

TABLE 5—Expenditures, 1949-1958, for expanding crude oil and natural gas production and reserves in Free World areas outside the United States.

	Million Dollars	Percent of Total
Canada	3,425	24.9
Venezuela	4,130*	30.0
Europe and Africa	1,875	13.6
Middle East	1,565	11.4
Far East	1,090	7.9
Other Countries	1,675	12.2
Total	13,760	100.0

* Includes $700 million for concession acquisitions in 1956—1957.

It is interesting to note that the U.S. industry spent $38.5 billion or nearly three times as much for expanding crude production as expended abroad. In contrast, crude production in this country during 1958 amounted to only 43 percent of the Free World output.

The rise in unit cost of maintaining and expanding crude production in the United States compared with other areas for the 10-year period 1949-1958 is shown in Table 6.

TABLE 6—Unit costs, 1949-1958, of maintaining and expanding crude oil production in the Free World.

Year	PER BARREL OF CRUDE PRODUCTION					
	United States	Canada	Venezuela	Middle East	Far East	Other Areas
1949	$1.20	$6.90	$0.76	$0.33	$1.16	$0.59
1950	1.18	6.99	0.30	0.13	0.70	0.45
1951	1.32	4.83	0.37	0.11	0.75	0.51
1952	1.58	5.47	0.42	0.17	0.88	1.03
1953	1.69	4.02	0.41	0.11	0.79	1.25
1954	1.86	4.01	0.39	0.11	0.82	1.21
1955	1.88	3.28	0.41	0.12	0.86	1.25
1956	1.94	2.85	0.81*	0.16	0.84	1.53
1957	1.95	2.61	0.95*	0.17	1.06	2.05
1958	1.73	2.51	0.58	0.21	0.88	2.31
Avg.	1.66	3.48	0.57	0.16	0.87	1.35

* Includes $0.35 and $0.38 per barrel respectively for concessions.

It should be understood that this computation does not give credit for natural gas and condensate produced. Revenue therefrom is important in the United States and is increasing in other areas also.

Deficit areas. In many areas and at different times, sums spent for exploration, production and development have exceeded by far the revenue from these areas from oil and gas sales. For instance, during 1948-1957, production and development expenditures in Canada amounted to $2.9 billion, which exceeded revenue by more than $1.2 billion, after providing for operating expenses.

Among other deficit areas, industry has spent more than $50 million in Australia, $75 million in Papua, $20 million in New Zealand, $25 million in Sarawak, $20 million in Pakistan, and $125 million in West New Guinea.

The Barco Concession in Colombia is a good example of a concession outside the United States which involved a very large investment and also many years before any return was realized. A total of 23 years and $60 million was expended before the first barrel of oil was marketed. The gross investment in production and pipe line facilities approximated $100 million at the close of 1957.

—The End

U.S. hydrocarbon reserves set new record

By Don E. Lambert
Associate Editor, WORLD OIL

U.S. OIL OPERATORS increased the nation's total proved recoverable reserves of crude oil and natural gas liquids to a new high during 1959. However, the ratio of liquid hydrocarbon reserves to annual production decreased slightly, from 13.5-1 in 1958 to 13.3-1 last year.

The reserve picture in brief:

- **Proved reserves of crude oil and natural gas liquids totaled 38.2 billion barrels last December 31, an increase of 1.5 billion barrels over 1958.**

- Operators proved up 4.4 billion barrels of new liquid hydrocarbon reserves through discoveries, extensions and revisions, for an increase of 903.7 million barrels over the total added in 1958.

- **Annual liquid hydrocarbon production totaled 2.87 billion barrels, up 154 million barrels over the 1958 total.**

- The nation's two leading petroleum states continue to set the pace in adding new reserves. Texas increased its liquid hydrocarbon reserve total nearly 576 million barrels to a new high of 18.3 billion barrels. Louisiana did even better, increasing its total nearly 778 million barrels to a record high of 6 billion barrels.

- **During the past five years (1954-1959), the four top liquid hydrocarbon states (Texas, Louisiana, California, Oklahoma) have increased their total proved reserves 1.36 billion barrels—from 28.26 billion barrels to 30.62 billion barrels. However, their share of the U.S. total has decreased, from 81.2 percent to 80.3 percent.**

- During the same period, four Rocky Mountain states (Wyoming, Utah, Montana, North Dakota) increased their share of U.S. total reserves from 5.4 percent to 6.8 percent. Their total reserves were increased

TABLE 1—Summary of Changes in 1958 in Proved Reserves of Liquid Hydrocarbons
Sources: Crude Oil from API; Natural Gas Liquids from API and AGA.
(THOUSANDS OF BARRELS)

	Crude Oil	Natural Gas Liquids	Total Liquid Hydrocarbons
Total proved reserves, December 31, 1958	30,535,917,000	6,204,018,000	36,739,935,000
Revisions of previous estimates and extensions of old pools	3,297,383,000	593,905,000	3,891,288,000
New reserves discovered in 1959 in new fields and in new pools in old fields	369,362,000	109,539,000	478,901,000
Proved reserves added in 1959	3,666,745,000	703,444,000	4,370,189,000
Total proved reserves as of December 31, 1958 plus new proved reserves added in 1959	34,202,662,000	6,907,462,000	41,110,124,000
*Less production during 1959	2,483,315,000	385,154,000	2,868,469,000
Total proved reserves, December 31, 1959	31,719,347,000	6,522,308,000	38,241,655,000
Change in reserves during 1959	+1,183,430,000	+318,290,000	+1,501,720,000

* The 1959 production figures were compiled by the committee from records of actual production for whatever period such were available, with estimates for the remainder of the year. Any variance between the actual production, as later reported, and the figures used herein will be compensated for through revision when the following year's reserve report is compiled. These revisions have in the past been very small. Because, in each annual report by this committee, the production figure for the year is an estimate, as just explained, correct total cumulative production cannot be obtained by adding together the figures listed in successive reports of this committee, or in the columns marked "production" of Tables 2 and 3.

TABLE 2—U.S. Petroleum Reserves Have Increased 10 Billion Barrels in 10 Years

	NEW OIL ADDED DURING YEAR					
	Revisions of Previous Estimates and Extensions to Known Fields (1)	Discoveries of New Fields and of New Pools in Old Fields (2)	Total New Discoveries, Extensions, and Revisions (Columns 1 + 2) (3)	*Production During Year (4)	Estimated Proved Reserves as of End of Year (Column 3—4) (5)	Increase Over Previous Year (6)
Crude Oil						
1946	2,413,628,000	244,434,000	2,658,062,000	1,726,348,000	20,873,560,000	931,714,000
1947	2,019,140,000	445,430,000	2,464,570,000	1,850,445,000	21,487,685,000	614,125,000
1948	3,398,726,000	396,481,000	3,795,207,000	2,002,448,000	23,280,444,000	1,792,759,000
1949	2,297,428,000	890,417,000	3,187,845,000	1,818,800,000	24,649,489,000	1,369,045,000
1950	1,997,769,000	564,916,000	2,562,685,000	1,943,776,000	25,268,398,000	618,909,000
1951	4,024,698,000	389,256,000	4,413,954,000	2,214,321,000	27,468,031,000	2,199,633,000
1952	2,252,860,000	496,428,000	2,749,288,000	2,256,765,000	27,960,554,000	492,523,000
1953	2,704,450,000	591,680,000	3,296,130,000	2,311,856,000	28,944,828,000	984,274,000
1954	2,287,231,000	585,806,000	2,873,037,000	2,257,119,000	29,560,746,000	615,918,000
1955	2,393,767,000	476,957,000	2,870,724,000	2,419,300,000	30,012,170,000	451,424,000
1956	2,507,114,000	467,222,000	2,974,336,000	2,551,857,000	30,434,649,000	422,479,000
1957	2,008,603,000	416,197,000	2,424,800,000	2,559,044,000	30,300,405,000	—134,244,000
1958	2,293,513,000	314,729,000	2,608,242,000	2,372,730,000	30,535,917,000	235,512,000
1959	3,297,383,000	369,362,000	3,666,745,000	2,483,315,000	31,719,347,000	1,183,430,000
Natural Gas Liquids						
1946					3,163,219,000	
1947	192,237,000	59,301,000	251,538,000	160,782,000	3,253,975,000	90,756,000
1948	405,874,000	64,683,000	470,557,000	183,749,000	3,540,783,000	286,808,000
1949	294,211,000	92,565,000	386,776,000	198,547,000	3,729,012,000	188,229,000
1950	707,879,000	58,183,000	766,062,000	227,411,000	4,267,663,000	538,651,000
1951	648,497,000	75,494,000	723,991,000	267,052,000	4,724,602,000	456,939,000
1952	475,170,000	81,668,000	556,838,000	284,789,000	4,996,651,000	272,049,000
1953	648,047,000	95,922,000	743,969,000	302,698,000	5,437,922,000	441,271,000
1954	20,830,000	86,520,000	107,350,000	300,815,000	5,244,457,000	—193,465,000
1955	447,160,000	67,348,000	514,508,000	320,400,000	5,438,565,000	194,108,000
1956	715,764,000	94,056,000	809,820,000	346,053,000	5,902,332,000	463,767,000
1957	8,884,000	128,508,000	137,392,000	352,364,000	5,687,360,000	—214,972,000
1958	749,956,000	108,250,000	858,206,000	341,548,000	6,204,018,000	516,658,000
1959	593,905,000	109,539,000	703,444,000	385,154,000	6,522,308,000	318,290,006
Total Liquid Hydrocarbons						
1946					24,036,779,000	
1947	2,211,377,000	504,731,000	2,716,108,000	2,011,227,000	24,741,660,000	704,881,000
1948	3,804,600,000	461,164,000	4,265,764,000	2,186,197,000	26,821,227,000	2,079,567,000
1949	2,591,639,000	982,982,000	3,574,621,000	2,017,347,000	28,378,501,000	1,557,274,000
1950	2,705,648,000	623,099,000	3,328,747,000	2,171,187,000	29,536,061,000	1,157,560,000
1951	4,673,195,000	464,750,000	5,137,945,000	2,481,373,000	32,192,633,000	2,656,572,000
1952	2,728,030,000	578,096,000	3,306,126,000	2,541,554,000	32,957,205,000	764,572,000
1953	3,352,497,000	687,602,000	4,040,099,000	2,614,554,000	34,382,750,000	1,425,545,000
1954	2,308,061,000	672,326,000	2,980,387,000	2,557,934,000	34,805,203,000	422,453,000
1955	2,840,927,000	544,305,000	3,385,232,000	2,739,700,000	35,450,735,000	645,532,000
1956	3,222,878,000	561,278,000	3,784,156,000	2,897,910,000	36,336,981,000	886,246,000
1957	2,017,487,000	544,705,000	2,562,192,000	2,911,408,000	35,987,765,000	—349,216,000
1958	3,043,469,000	422,979,000	3,466,448,000	2,714,278,000	36,739,935,000	752,170,000
1959	3,891,288,000	478,901,000	4,370,189,000	2,868,469,000	38,241,655,000	1,501,720,000

*See note bottom of table 1.

722.3 million barrels, to 2.6 billion barrels.

These statistics are based on the 1958 annual liquid hydrocarbon and natural gas reserve report prepared by the American Petroleum Institute.

Crude reserves at new high. Oil operators increased the U.S. crude oil reserve total 1.2 billion barrels, to a new high of 31.7 billion barrels during 1959. This represented the largest net increase since 1951.

However, the ratio of crude oil reserves to production was down slightly, from 12.9-1 on Dec. 31, 1958 to 12.8-1 on the same date last year.

A major factor in the large net increase in crude oil reserves during 1959 was the 3.7 billion barrels of new reserves added through discoveries, extensions and revisions. This was the largest total of new reserves added since the record year of 1951, when 4.4 billion barrels of new reserves were added to the nation's total.

Natural gas liquids. U.S. reserves of natural gas liquids totaled 6.5 billion barrels at the end of last December, up 318.3 million barrels over the total reported on the same date in 1958.

New reserves proved up during 1959, including extensions and revisions, totaled 703.4 million barrels, compared with the 858.2 million barrels proved up during 1958. Discoveries of new fields and pools during 1959 added 109.5 million barrels to the nation's reserves. This compares with 108.3 million barrels in 1958 and 128.5 million barrels in 1957.

The ratio of natural gas liquids reserves to annual production was 16.9-1 last December 31, compared with 18.2-1 on the same date in 1958.

Louisiana sets record. The nation's second largest reserve state continued to increase its share of total U.S. liquid hydrocarbon reserves last year, with an increase of 777.9 million barrels to a record total of 6 billion barrels, 15.7 percent of the U.S. total. In 1958, Louisiana accounted for 14.3 percent, and in 1957, 13.5 percent.

Texas, the nation's largest reserve state, continues to account for a smaller share of the U.S. liquid hydrocarbon reserves. The 18.3 billion barrels reported last December 31 was 47.8 percent of the nation's total, compared with 48.3 percent in 1958 and 49.5 percent in 1957.

Of the 23 U.S. producing areas, 12 reported decreases in total reserves last year—with California topping the list, reporting a drop of 80.9 million barrels. Only eight states reported decreases in 1958. —The End

TABLE 3—Estimated Proved Reserves of Liquid Hydrocarbons in U.S., by States
Sources: Crude Oil from API and Natural Gas Liquids from API and AGA.
(THOUSANDS OF BARRELS)

STATE or PROVINCE	Proved Reserves Dec. 31, 1958	Added in 1959 by Extensions and Revisions	[2]Discovered in New Fields and New Pools in Old Fields in 1959	[3]Production During 1959	Proved Reserves Dec. 31, 1959 (Columns 1 + 2 + 3 Less Column 4)	Changes in Reserves During 1959 (Column 5 Less Column 1)
	(1)	(2)	(3)	(4)	(5)	(6)
[2]Crude Oil						
Alabama	38,586	1,271	.....	5,609	34,248	(—) 4,338
Arkansas	317,865	18,794	1,074	24,822	312,911	(—) 4,954
[4]California	3,866,430	195,155	8,080	307,158	3,762,507	(—)103,923
Colorado	392,060	32,374	2,630	46,112	380,952	(—) 11,108
Illinois	607,589	60,856	2,539	76,577	594,407	(—) 13,182
Indiana	71,469	12,679	1,278	11,475	73,951	2,482
Kansas	922,434	96,918	17,089	118,938	917,503	(—) 4,931
Kentucky	126,357	30,965	7,252	28,250	136,324	9,967
[4]Louisiana	4,043,993	800,459	133,993	318,357	4,660,088	616,095
Michigan	44,968	16,689	4,213	10,535	55,335	10,367
Mississippi	378,688	43,644	14,336	47,331	389,337	10,649
Montana	337,799	(—) 1,464	3,300	30,367	390,268	(—) 28,531
Nebraska	69,242	28,326	5,700	22,710	80,558	11,316
New Mexico	894,121	222,100	11,909	102,341	1,025,789	131,668
New York	35,803	360	.....	1,966	34,197	(—) 1,606
North Dakota	314,079	80,598	5,100	17,868	381,909	67,830
Ohio	70,809	9,320	.....	5,992	74,137	3,328
Oklahoma	1,898,128	144,018	16,049	193,446	1,864,749	(—) 33,379
Pennsylvania	119,832	—100	.....	6,158	113,574	(—) 6,258
[4]Texas	14,322,216	1,346,675	129,784	939,001	14,859,674	537,458
Utah	198,639	35,655	207	39,962	194,539	(—) 4,100
West Virginia	52,104	1,320	.....	2,165	51,259	(—) 845
Wyoming	1,408,717	114,865	4,679	125,323	1,402,938	(—) 5,779
[8]Miscellaneous	3,989	5,906	150	852	9,193	5,204
Total Crude Oil	30,535,917	3,297,383	369,362	2,483,315	31,719,347	1,183,430
[6]Natural Gas Liquids						
[7]Alabama	.....	.....	.....	.....	.....	.....
Arkansas	34,150	148	302	2,583	32,017	(—) 2,133
[4]California	302,319	51,572	535	29,108	325,318	22,999
Colorado	21,268	7,273	78	3,705	24,914	3,646
Illinois	10,950	111	1,250	1,557	10,754	(—) 196
Indiana	119	23	1	19	124	5
Kansas	199,552	3,210	623	6,473	196,912	(—) 2,640
Kentucky	37,472	13,612	1,492	3,286	49,290	11,818
[4]Louisiana	1,195,955	203,094	32,201	73,452	1,357,798	161,843
Michigan	1,502	189	27	156	1,562	60
Mississippi	55,182	(—)12,286	721	2,673	40,944	(—) 14,238
Montana	7,497	6,667	.....	653	13,511	6,014
Nebraska	5,699	516	.....	783	5,432	(—) 267
New Mexico	417,238	16,004	8,886	19,088	423,040	5,802
North Dakota	31,239	68,108	.....	1,419	97,928	66,689
Ohio	1,618	—314	.....	.....	1,304	(—) 314
Oklahoma	357,507	34,481	3,900	28,319	367,569	10,062
Pennsylvania	3,685	40	20	68	3,677	(—) 8
[4]Texas	3,391,967	184,496	57,225	203,313	3,430,375	38,408
Utah	14,899	17,948	.....	471	32,376	17,477
West Virginia	63,286	(—)28,185	2,171	3,106	34,166	(—) 29,120
Wyoming	50,876	27,215	107	4,919	73,279	22,403
[8]Miscellaneous	38	—17	.....	3	18	(—) 20
Total Nat. Gas Lq.	6,204,018	593,905	109,539	385,154	6,522,308	318,290
Total Liquid Hydrocarbons						
[9]Alabama	38,586	1,271	.....	5,609	34,248	(—) 4,338
Arkansas	352,015	18,942	1,376	27,405	344,928	(—) 7,087
[4]California	4,168,749	246,727	8,615	336,266	4,087,825	(—) 80,924
Colorado	413,328	39,647	2,708	49,817	405,866	(—) 7,462
Illinois	618,539	60,967	3,789	78,134	605,161	(—) 13,378
Indiana	71,588	12,702	1,279	11,494	74,075	2,487
Kansas	1,121,986	100,128	17,712	125,411	1,114,415	(—) 7,571
Kentucky	163,829	44,577	8,744	31,536	185,614	21,785
[4]Louisiana	5,239,948	1,003,553	166,194	391,809	6,017,886	777,938
Michigan	46,470	16,878	4,240	10,691	56,897	10,427
Mississippi	433,870	31,358	15,057	50,004	430,281	(—) 3,589
Montana	345,296	5,203	3,300	31,020	322,779	(—) 22,517
Nebraska	74,941	28,842	5,700	23,493	85,990	11,049
New Mexico	1,311,359	238,104	20,795	121,429	4,448,829	137,470
[9]New York	35,803	360	.....	1,966	34,197	(—) 1,606
North Dakota	345,318	148,706	5,100	19,287	479,837	134,519
Ohio	72,427	9,006	.....	5,992	75,441	3,014
Oklahoma	2,255,635	178,499	19,949	221,765	2,232,318	(—) 23,317
Pennsylvania	123,517	—60	20	6,226	117,251	(—) 6,266
[4]Texas	17,714,183	1,531,171	187,009	1,142,314	18,290,049	575,866
Utah	213,538	53,603	207	40,433	226,915	13,377
West Virginia	115,390	(—)26,865	2,171	5,271	85,425	(—) 29,965
Wyoming	1,459,593	142,080	4,786	130,242	1,476,217	16,624
[10]Miscellaneous	4,027	5,889	150	855	9,211	5,184
Total U.S.	36,739,935	3,891,288	478,901	2,868,469	38,241,655	1,501,720

[1] Crude oil figures include all condensate that comes out of separator. Other condensate is included in figures on natural gas liquids. [2]Limited area assigned to a discovery until proved larger. [3] See footnote to Table 1. [4] Includes offshore reserves. [5] Alaska, Arizona, Florida, Missouri, Nevada, South Dakota, Tennessee, Virginia, Washington. [6] Condensate, natural gasoline, LPG. [7] Included in "Miscellaneous." [8] Includes Alabama, Florida, Missouri. [9] Crude oil only. [10] Alabama, natural gas liquids; Alaska, Arizona, Nevada, South Dakota, Tennessee, Virginia, Washington crude; Florida, Missouri crude, natural gas liquids.

U.S. gas reserves increase 3.3 percent

SUBSTANTIAL INCREASES in U.S. natural gas reserves during 1959 brought total reserves to another all-time high. New reserves at the end of the year totaled 262.6 trillion cubic feet and represented an increase of 8.5 trillion cubic feet over reserves existing at the end of 1958. This compares with the 1958 gain of 7.6 trillion cubic feet and 8.8 trillion cubic feet in 1957.

Production during the year, amounting to 12.4 trillion cubic feet, showed a remarkable jump of 960 billion cubic feet over the previous year's figure. This contrasts sharply with the drop, in 1958, of 17.3 billion cubic feet as compared with 1957.

New pools and fields found during 1959 accounted for 5.8 trillion cubic feet, slightly more than the 1958 figure of 5.6 trillion, but still substantially under 1957 when 9 trillion cubic feet were proved.

During the year, 14.9 trillion cubic feet were accounted for in field extensions and revisions of earlier estimates. This represented an increase of 1.5 trillion cubic feet over the like 1958 period.

The 1959 figures indicate that, for the past three years, additions to reserves in the U.S., from new fields, extensions and revisions, have held fairly constant. Total reserves from these categories amounted to 20.7 trillion cubic feet in 1959, 19 trillion in 1958 and 20.1 trillion in 1957.

Still holding first place in total reserves, Texas and Louisiana together in 1959 showed a 10.2 trillion cubic feet gain over 1958, or nearly one-half of the 20.7 trillion cubic feet gain in reserves for the nation as a whole. New field discoveries, extensions and revisions in these two states totaled 18.7 trillion cubic feet, amounting to 90.3 percent of the total additions for the nation. During 1958, Texas and Louisiana new additions amounted to 84 percent of the nation's total of new gas found.

Total net gas production during 1959, for Texas and Louisiana, totaled 8.6 trillion cubic feet, or about 69.3 percent of the output of the entire nation.

During 1959, total reserves of six states dropped below their 1958 levels. A similar number of states, in 1958 reflected a drop in reserves as compared to 1957 figures. —**The End**

TABLE 1—Summary of Changes in 1959 in Proved U.S. Reserves of Natural Gas

(Source: American Gas Association)
Millions of cubic feet—14.65 psia, at 60° F.

Total proved reserves December 31, 1958	254,142,037
Extensions and revisions of previous estimate during 1959	14,933,109
New reserve discovered in 1959	5,800,749
Net changes in underground storage during 1959	161,326
Total proved reserves added and net changes in underground storage during 1959	20,895,184
Total proved reserves, December 31, 1958 and additions during 1959	275,037,221
Deduct production during 1959	12,440,628
Total proved reserves of natural gas, December 31, 1959	262,596,593

TABLE 2—Estimated Proved Recoverable Reserves of Natural Gas in U.S., by States

Source: American Gas Association
(Millions of Cubic Feet—14.65 psia, at 60° F.)

		CHANGES IN RESERVES DURING 1959				[1]RESERVES AS OF DECEMBER 31, 1959				
STATE	[1]Reserves As of December 31, 1958	[1]Extensions and Revisions	[1]Discoveries of New Fields and New Pools in Old Fields	[1]Net Change in Underground Storage	[2]Net Production	Total (Columns 7+8+9+10 Also Columns 1+2+3+4 Less Column 5)	[4]Non-Associated	[5]Associated	[6]Dissolved	[7]Underground Storage
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
Arkansas	1,388,337	**38,634**	60,981	(—) 41	65,094	**1,422,817**	929,225	288,939	199,822	4,831
[8]California	8,966,522	**39,321**	56,230	(—)2,787	465,839	**8,593,447**	2,155,750	2,011,601	4,335,078	91,018
Colorado	2,349,240	**236,396**	26,266	164	115,907	**2,496,159**	1,839,459	96,175	560,361	164
Illinois	170,528	**11,655**	279	11,112	18,464	**175,110**	11,089	0	118,881	45,140
Indiana	30,569	**4,682**	186	3,444	3,793	**35,088**	1,300	1,350	22,185	10,253
Kansas	20,233,847	**279,359**	97,365	9,895	639,063	**19,981,403**	19,155,537	407,100	356,064	62,702
Kentucky	1,215,329	(—) **4,467**	12,810	3,709	68,000	**1,159,381**	1,059,322	0	75,866	24,193
[8]Louisiana	55,111,862	**6,100,270**	1,509,830	0	2,868,042	**59,853,920**	48,135,211	8,248,993	3,469,716	0
Michigan	489,113	**17,877**	5,400	13,442	19,429	**515,403**	116,255	55,159	58,730	285,259
Mississippi	2,598,377	(—) **16,750**	68,031	1,571	164,705	**2,486,524**	1,805,406	372,200	303,380	5,538
Montana	682,013	(—) **3,155**	14,358	3,691	31,416	**665,491**	494,850	38,863	90,721	41,057
Nebraska	143,321	**2,623**	238	0	13,463	**132,719**	99,249	12,609	20,861	0
New Mexico	21,180,020	(—)**2,758,846**	196,341	(—)2,203	702,514	**17,912,798**	12,722,502	3,524,188	1,618,367	47,741
New York	96,439	**8,925**	1,575	3,717	4,137	**106,519**	48,801	0	158	57,560
North Dakota	1,124,470	**97,481**	0	0	15,409	**1,206,542**	9,997	340,498	856,047	0
Ohio	818,052	(—) **60,859**	11,170	16,714	36,311	**748,766**	325,000	0	87,000	336,766
Oklahoma	15,206,769	**1,878,770**	510,753	11,096	956,096	**16,651,292**	11,097,644	1,991,355	3,456,676	105,617
Pennsylvania	870,014	**217,298**	35,180	48,342	118,862	**1,051,972**	622,676	0	25,040	404,256
[8]Texas	115,045,743	**8,228,792**	2,887,699	5,004	5,691,455	**120,475,783**	78,166,487	26,932,160	15,332,872	44,264
Utah	1,058,051	**176,088**	74,372	0	44,261	**1,264,250**	799,877	25,640	438,733	0
Virginia	38,421	**2,125**	375	0	2,289	**38,632**	38,632	0	0	0
West Virginia	1,557,633	**174,386**	33,000	14,532	186,000	**1,593,551**	1,270,624	0	64,633	258,294
Wyoming	3,649,818	**254,558**	145,434	(—) 102	202,644	**3,847,064**	3,156,424	155,890	514,326	20,424
[9]Miscellaneous	108,549	**7,946**	52,876	20,026	7,435	**181,962**	109,170	0	16,673	56,119
Total	254,142,037	**14,933,109**	5,800,749	161,326	12,440,628	**262,596,593**	184,170,487	44,502,720	32,022,190	1,901,196

[1] Excludes gas loss due to natural gas liquids recovery. [2] The net difference between gas stored in and gas withdrawn from underground storage reservoirs, inclusive of adjustments and native gas transferred from other reserve categories. [3] Net production equals gross withdrawals less gas injected into producing reservoirs. Changes in underground storage and gas loss due to natural gas liquids recovery are excluded. Fourth quarter production estimated in some instances. [4] Non-associated gas is free gas not in contact with crude oil in the reservoir; and free gas in contact with oil where the production of such gas is not significantly affected by the production of crude oil. [5] Associated gas is free gas in contact with crude oil in the reservoir where the production of such gas is significantly affected by the production of crude oil. [6] Dissolved gas is gas in solution with crude oil in the reservoirs. [7] Gas held in underground reservoirs (including native and net injected gas) for storage purposes. [8] Includes off-shore reserves. [9] Includes Alabama, Alaska, Arizona, Florida, Iowa, Maryland, and Missouri.

Mexico is expanding its oil industry

By L. J. Logan
Associate Editor, WORLD OIL

POWERED AND LED by an energetic, progressive petroleum industry, modern Mexico is a wonderful land where immense opportunity is being turned into realities of growing industrial strength and better living for millions of people. In a world that elsewhere grows older and crowded, it is a frontier, where industry is young and empire building is under way.

Transformed largely by oil and gas into an increasingly industrial, commercial, and mobile nation, Mexico is no longer the land of *manana* (tomorrow), where things to be done can wait until later. It is now a country where work must be done today, and tomorrow must bring the fulfillment of plans for a stronger, more prosperous, happier nation.

Mexico is rich in natural resources and blessed with highly desirable climate. Its people are energetic and its national and industrial leaders imaginative and able. Mexico has all the requisites for a great nation, and is fashioning them into a nation of that kind. Mexico is the third most populous country of the Western Hemisphere, and in its work and plans it is determined to fill that important position responsibly and creditably.

A new and stronger Mexico is arising. It formerly consisted largely of two classes of people: several million of the rich, ruling class and the remaining millions of peons. Now there is a vast and growing middle class of about 9 million out of a total population of some 33 million. As Mexico expands industrially and commercially, the middle class grows in number, and higher standards of living spread throughout the nation. The country is in the midst of an industrial revolution, which brings with it an economic and social revolution, all for the advancement and betterment of the nation.

Writers on Tour. This writer during the first half of March 1960 had the privilege and pleasure of thoroughly seeing Mexico's petroleum industry and learning about its operations from many officials, managers, engineers, geologists, and others connected with Petroleos Mexicanos, the government company that carries out oil and gas development. Nearly a dozen representatives of about the same number of U.S. petroleum industry publications made this visit, which was sponsored by Petroleos Mexicanos. Antonio Vargas MacDonald, Pemex coordinator of public relations, was in charge of the tour.

On the extensive trip by plane the visitors saw oil and gas fields, pipe lines, natural gasoline plants, refineries, marine terminals, service stations, and other petroleum industry installations, from Reynosa near the Texas border down to Ciudad Pemex in the Isthmus. Pemex headquarters in Mexico City were visited, and Pemex operations, expansion and plans were discussed in a press interview by Pascual Gutiérrez Roldán, engineer, financier, and general manager of Petroleos Mexicanos since December 1, 1958.

In addition to the petroleum properties, the visitors toured two important steel plants, which supply Pemex with tubular goods and other steel products.

Eight to 12 new petrochemical plants will be under construction in Mexico in 1960, according to the Pemex general manager. They will produce three main classes of products: ammonia, carbon black, and artificial fibres. By May, 48 new drilling rigs will go into operation in Mexico, including 14 already on the way. Pemex heretofore has been operating 96 drilling rigs. Programmed for 1960 are 117 exploratory wells and 506 development wells.

A large gas pipe line is being built between Ciudad Pemex in the Isthmus and Mexico City, with two contractors at work on it. A gas line from Reynosa to Monterrey is being extended to Torreon, and the extension is due to be completed in April.

Five new petroleum equipment companies are now operating in Mexico, having been formed by U. S. interests as Mexican corporations. These include affiliates of Cameron Iron Works, Wyatt Metal & Boiler Works, Hughes Tool Company.

Plants making synthetic fibres, ammonium nitrate, etc. will be independent companies, privately controlled. Pemex will supply them with raw materials.

Petroleos Mexicanos has for 1960 a budget of 8 billion pesos ($640 million). That is almost as much as the budget of 10 billion pesos ($800 million) scheduled by Mexico's federal government.

The refineries now operated in Mexico are all modern and efficient. They have a combined crude capacity of about 380,000 barrels per day, and are constantly being expanded. They will have 20 percent more capacity than needed by next June. To use that extra capacity, some foreign crude may be brought in, processed and exported.

The fields of Mexico are producing about 300,000 barrels per day of crude oil and natural gas liquids, including between 15,000 and 20,000 of the latter. The production fulfills Mexico's domestic demand for petroleum and includes exports of heavy crudes and residual fuel oil.

In Mexico the demand for petroleum, steel, detergents, and many other materials increases fantastically. Detergents were made initially without any material known demand, but full production was quickly absorbed by newly created demand. The demand for gasoline and distillate fuels has been increasing 7½ percent per year for all Mexico and 12 percent annually in Mexico City. Production of fertilizers in new ammonia plants readily develops markets. Synthetic rubber will be made at Tampico, and demand for it is expected to be strong. Mexico's population is increasing 3.5 percent per year, and standards of living are rising.

To keep abreast of the sharply increasing demand for petroleum products and petrochemicals, Petroleos Mexicanos must constantly plan ambitiously and keep vigorous expansion of all facilities under way. It is actively searching for new oil and gas fields, keeping numerous geophysical and geological parties at work, and drilling as many wildcats as available funds

permit. More oil and gas pipe lines and products lines are being built. Every refinery and natural gasoline plant has space set aside for expansion.

While Pemex requires vast funds for operations and expansion, it also has large income from the products it supplies the country. The production amounts to about 300,000 barrels per day, and potential production of 320,000 barrels daily is available. The company's income may be enough to finance required expansion. If necessary, Pemex can and will finance essential projects by obtaining loans from banks and other sources in the United States or other countries.

Like private oil companies, Pemex generates capital from its own operations and has valuable assets on which it can readily borrow money.

Pemex formerly paid the Mexican government various taxes. But in lieu of them it now pays one blanket tax of 12 percent of its gross income. Indirectly, Pemex also performs many functions usually carried out by governments, including the building of some roads that can be used by the public as well as Pemex.

To facilitate balancing of its budget, Pemex last year increased its prices of gasoline, diesel oil, and other products. They had been so low as to result in losses for Pemex. Despite the increases, however, prices are still very reasonable. For top grade gasoline at Poza Rica the motorist pays 80½ centavos per liter, equivalent to about 26 cents U. S. per gallon total price, no tax being involved.

In late March, 1960, Pemex was due to issue its second annual report, having initiated this public accounting of its operations a year ago.

Last August Pemex negotiated a new 3-year labor contract with the labor union, and relations between the company and the union are favorable.

Mexico has proved oil reserves of 2½ billion barrels, including crude oil and distillate. It has gas reserves equal in energy value to 1½ billion barrels.

The production of 300,000 barrels of oils per day comes from about 2,200 wells, of which 1,500 are flowing and 700 artificially lifted. About 200 gas wells are on production, being in Northeast Mexico and the Isthmus.

During the past five years 325 strict wildcats were drilled in Mexico. They resulted in discovery of 67 new oil and gas fields. In Mexico 45 exploration parties operated in 1958, including 22 subsurface geology crews, 18 seismic crews, and 5 gravity meter crews.

L. J. Logan (left) associate editor of World Oil, **is shown here with Antonio Vargas MacDonald, coordinator of public relations for Petroleos Mexicanos, as visiting U.S. journalists arrived on a Pemex plane at Mexico City.**

More about Mexico next month

In the May issue, World Oil will present additional, detailed information on Mexico's petroleum industry. A map will show oil and gas fields, pipe lines, absorption plants, refineries. Information will be given on the drilling program for 1960, drilling rigs employed, producing wells, oil and gas production, pipe line construction, etc.

Following the tour of Mexico's petroleum and steel industry installations, the representatives of U. S. petroleum industry publications were asked by Julián Carlos y Jiménez, reporter for *Excelsior*, Mexico City daily newspaper, who made the whole trip, for an exclusive joint statement expressing their impressions of Mexico's petroleum industry. Such a statement was prepared and unanimously approved as accurately reflecting the opinions of the U. S. men who made the trip. Following is a copy of that statement, as issued for publication in *Excelsior*.

"Mexico's petroleum industry, under the management of Petroleos Mexicanos, is obviously taking a very important part in making Mexico a progressive, well advanced country, with an unusually promising future.

"After seeing many of Mexico's oil and gas industry installations and some of its steel and pipe making plants, it is evident that Mexico is succeedingly remarkably well in taking advantage of its natural resources and in building up its industrial strength.

"Mexico is fortunate in having rich petroleum resources. And it is effectively putting those resources to the use of its people.

"Petroleum industry operations in Mexico are well planned and well managed. Oil and gas field installations, refineries, pipe lines, and other properties are similar to those in the United States and equally well engineered and maintained.

"In all districts, Petroleos Mexicanos has numerous well educated, well trained engineers, geologists, and other personnel who assure efficient handling of operations. Many of these men are young, and they represent a great asset. In so far as more engineers, geologists, geophysicists, and other necessary technically trained young men are brought into Mexico's petroleum industry, progressive and efficient operations will be promoted.

"The petroleum industry in Mexico also is fortunate in having very able leaders and managers," the statement continued. "They are planning further broad expansion and advancement of oil and gas development. They recognize that Mexico's demand for oil and gas is increasing sharply, and are vigorously working toward always fulfilling that demand.

"The visitor notices that in every district, space has been provided for additional new refinery units, gasoline plant units, housing for workers and managers, and other facilities.

"On all sides there is evidence of a growing, expanding, progressive petroleum industry. And similar progress is evident at the steel plants, pipe mills, and related industries that provide essential supplies and materials for Mexico's petroleum industry.

"It does not require a prophet but only an awake visitor," concluded the statement, "to foresee for Mexico an increasingly strong petroleum industry, supplying more and more oil and gas for a nation that will continue to grow and advance vigorously."

TO BE CONTINUED

New type rotary rig drive proves successful

Rig motors transmit power to drawworks by torque shafts with universal joints

FIGURE 1—Over-all view of a new type German rig.

By S. Lechler, Engineer
Mobil Oil Company A.G. of Germany

A NEW TYPE GERMAN rotary drilling rig is presently being operated successfully after several months of field testing.

This rig offers several new design and layout features. They are:

- All engines are equipped with disengaging torque converters.
- Mud pumps are equipped with swing-gears to protect the prime mover from pump shocks.
- Torque converters are equipped with temperature and overspeed governors.
- Jaw clutches are used instead of chain drives.

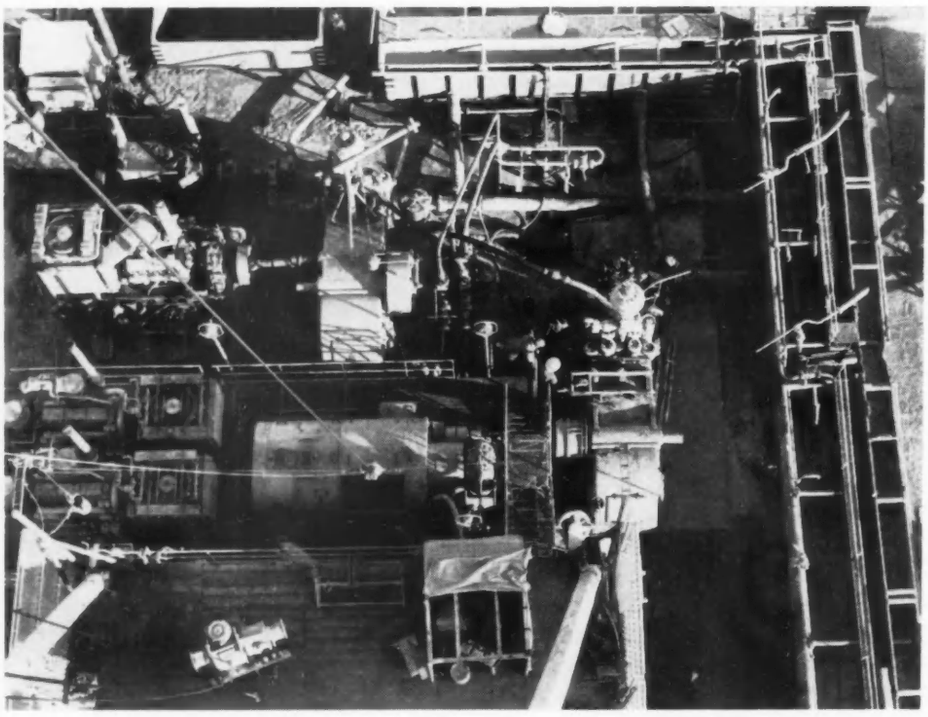


FIGURE 2—A top view of the entire rig is shown while drilling.

The drawworks is rated at 900 horsepower with the power being supplied by two 600-horsepower water-cooled supercharged diesels. The rotary is powered by a separate 250-horsepower air cooled supercharged diesel while the stand-by pump is equipped with an 800-horsepower motor. The total horsepower available on the rig is more than 2,300-continuous horsepower. Depth limitation for this rig is 15,000 feet with 4½-inch drill pipe and 20,000 feet with 3½-inch drill pipe.

The engines are all equipped with disengaging converters with the exception of the rotary drive. To serve the drawworks, a four-speed-reduction-gear box with a reverse gear is

directly connected to the torque converter in one housing. The gear selection in this unit is by means of overrunning jaw clutches. The two main rig motors transmit power to the drawworks by torque shafts with universal joints and are compounded by a reduction gear inside the drawworks to drive either the hoisting drum, or by means of a separate drive, the rig mud pump. Either power package may be switched so that either the pump or drawworks may be independently operated.

Torque unit used as a brake. The torque converter disengagement is achieved hydraulically, eliminating any friction clutch. Since the torque converter is used as the braking element, no special hydromatic brake is necessary. While using this type of braking device, maintenance cost is rapidly reduced. During the field testing operations, no wear was observed for a period of one year on either the brake rim nor the bands of the drawworks. To supplement this type of braking, the mechanical brake is used in order to hold the load fast.

The over-all weight of the drawworks, hydromatic brake, prime movers, torque converters, gear box and compound-skid, is approximately 85,000 pounds. The hoisting capacity is 63,000 pounds at a speed of 6.5 feet per second.

The torque converters are protected by temperature and overspeed governors. When a predetermined temperature, or when the output of the torque converter exceeds a predetermined figure, the engine is automatically placed in an idling condition. By doing this, optium efficiency is maintained.

Separate rotary drive. A separate rotary drive, powered by a 250-horsepower engine, guarantees more flexibility for drilling operations. A torque converter with variable pitch blades and a two-speed reduction gear is used to provide the adaptability to meet all possible drilling conditions.

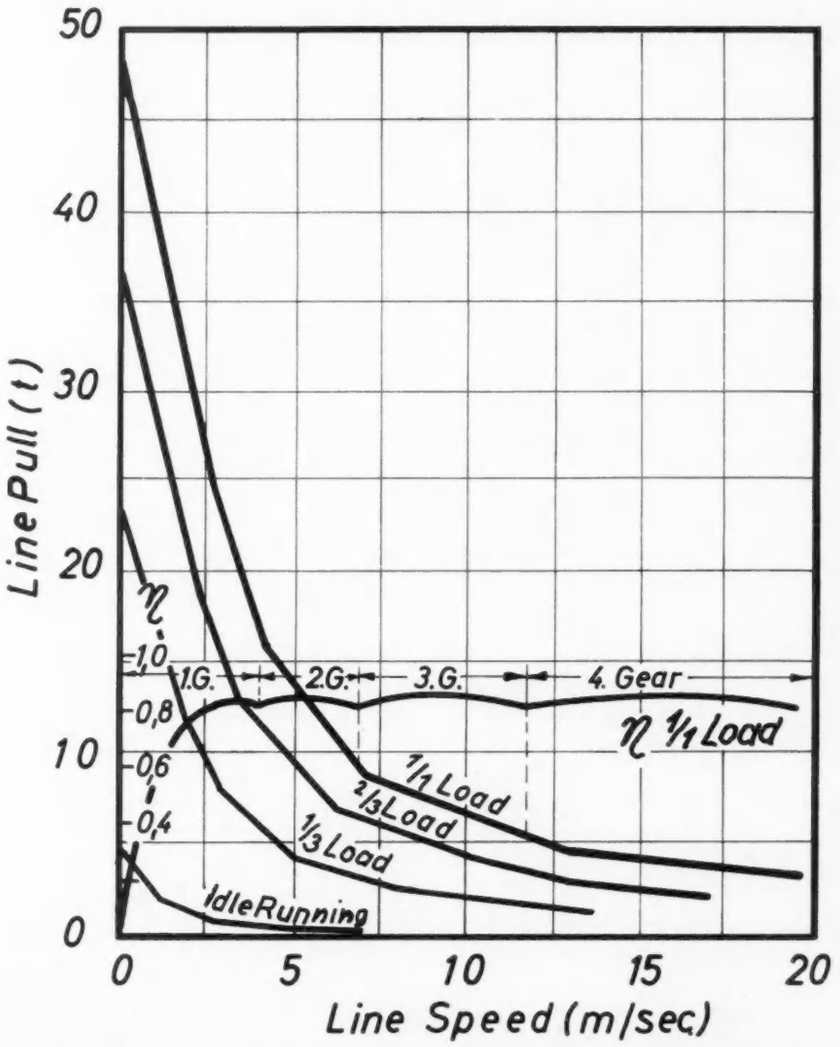


FIGURE 3—These curves show the respective line pull and efficiency of the drawworks.

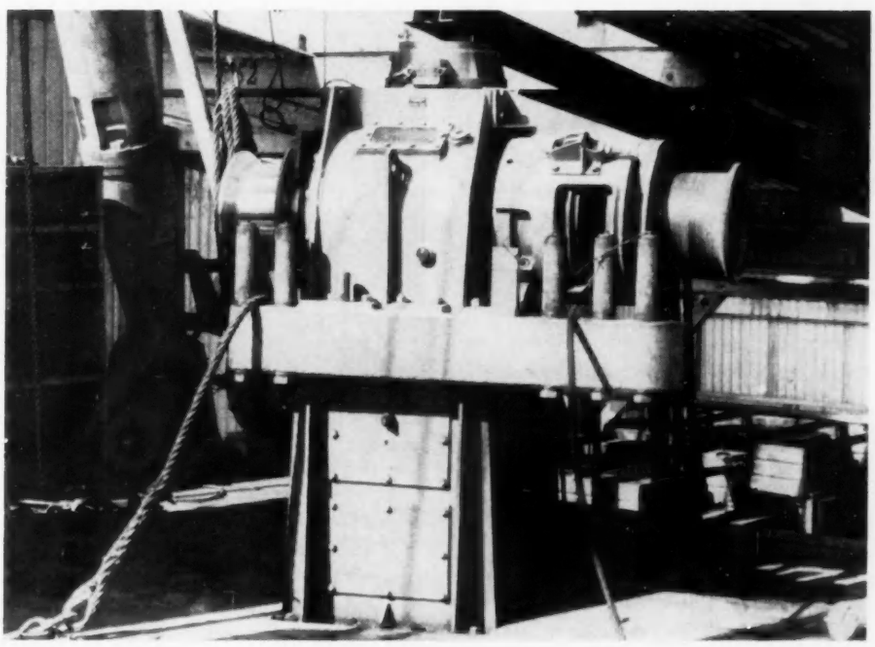


FIGURE 4—An independent electrically driven cathead is used rather than the conventional drawworks-cathead installation.

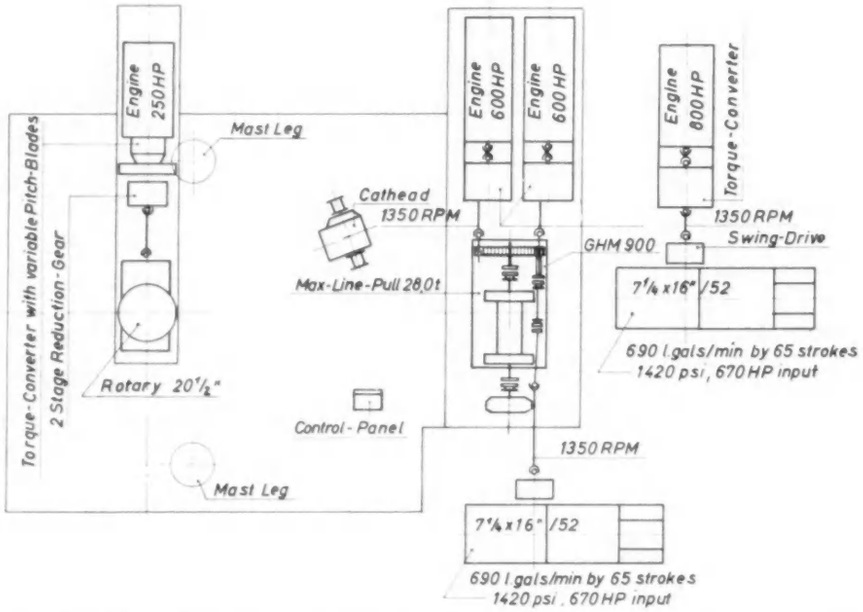


FIGURE 5—Here is shown a schematic layout of the equipment and their respective unit capacities.

About the Author

S. Lechler was graduated from University of Brunswick in 1938 with a degree in mechanical engineering. After World War II, he worked eight years in the German Petroleum Institute at Hannover as a scientific assistant. His work included the determination of physical properties of reservoir fluids under reservoir conditions. He is presently a senior petroleum engineer with Mobil Oil A.G. in Deutschland, Crude Oil Department, an affiliate of Socony Mobil Oil Company, New York. His present work includes different problems of drilling and production practices.

The prime mover is skid mounted and is connected to the rotary table by universal joints.

Safety is of prime interest while operating the cathead. A small electric hoist, torque rated in 8 steps, is placed on the working platform close to the driller's control and is used for all catheading operations. This enables the driller to watch the cathead man directly without having to direct his attention away from the area of operation.

Mud pump's power is unique. All mud pumps are equipped with swing gears to protect the prime mover from pump shocks, to regulate the input torque and to reduce the output speed of the torque converter. When a predetermined torque of the engines are reached, the engines are automatically placed in the idling speed position. By using this driving method, clutches are no longer necessary in pump drives. The torque converter and torque shafts are used for the power transmission.

The driller's controls are grouped on a console panel at one corner of the derrick floor. Air type remote controls are employed with unitized air line connections which are easily connected (See Figure 6).

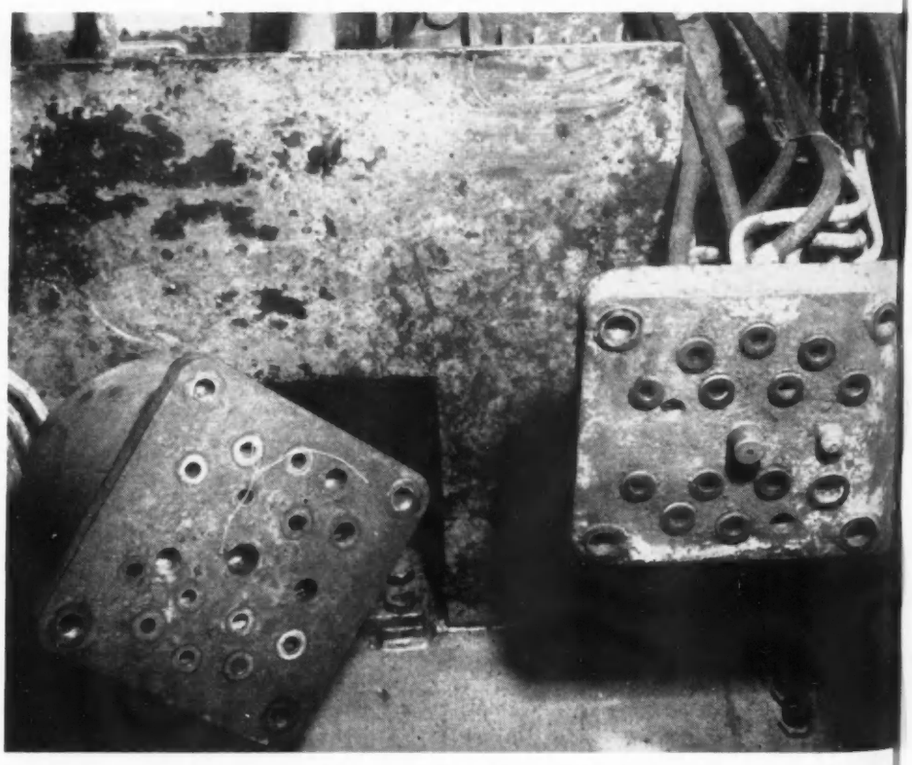


FIGURE 6—General view and close-up of quick coupling for air supply to drillers console.

The over-all design of the rig places all the heavy components at ground level, with the exception of the drawworks and its prime movers. These are located at truck-height for the ease of transportation. Flexible hoses have been used wherever possible for rig-piping to provide a fast coupling and uncoupling as well as ease of traveling. To satisfy road-width requirements, all major equipment except the derrick is mounted on skids. **—The End**

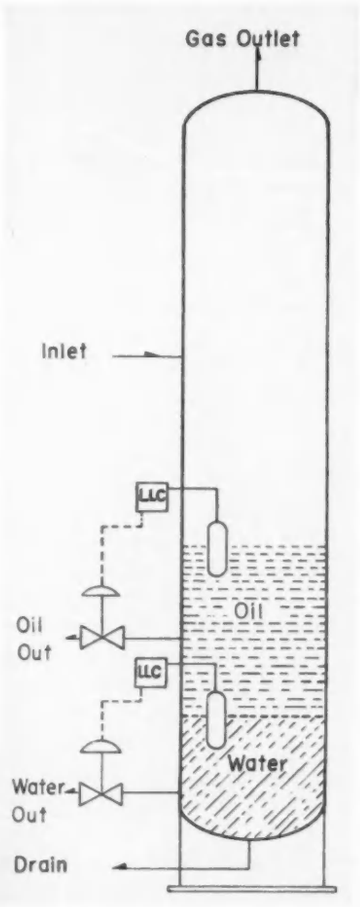


FIGURE 1—Vertical vessel. Three-phase operation obtained through use of level controls only.

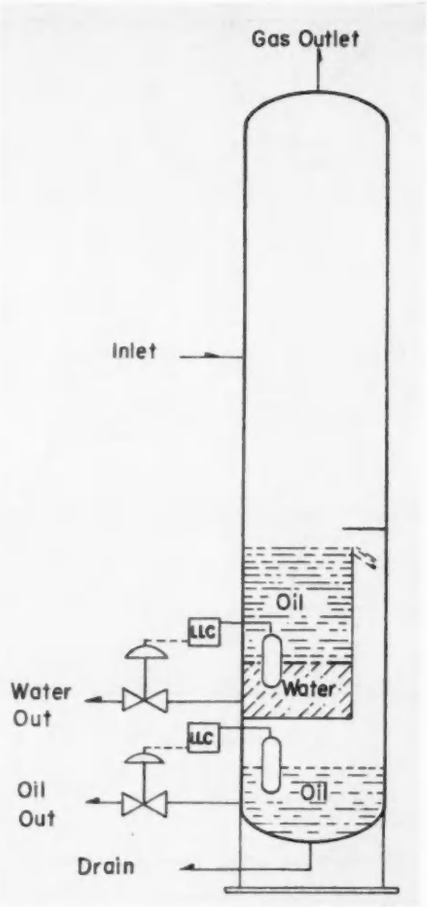


FIGURE 2—Vertical vessel. Three-phase operation obtained by interfacial level control and weir.

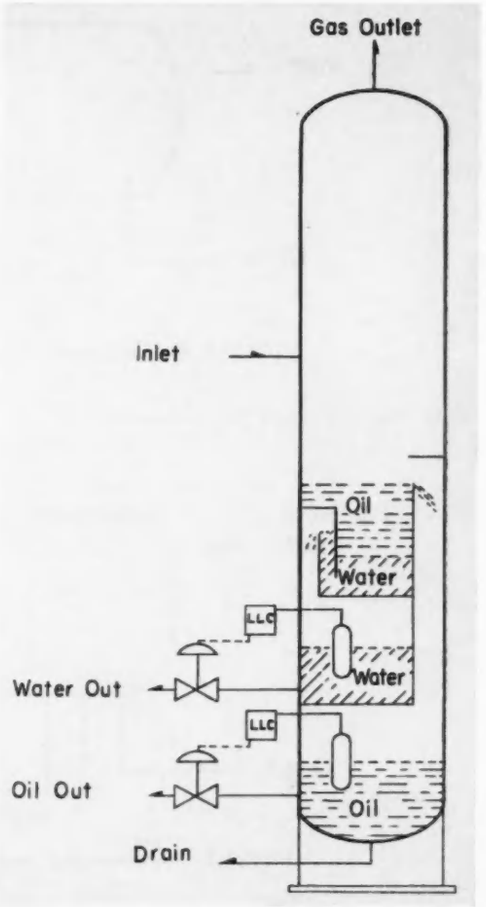


FIGURE 3—Vertical vessel. Three-phase operation obtained by use of weir to control main liquid level. Interfacial level in main section is controlled by a water weir.

10. THREE-PHASE SEPARATORS

By Wilbur F. Broussard, Engineer
Maloney Crawford Tank and Manufacturing Co., Houston

Charles K. Gravis, Engineer
Maloney Crawford Tank and Manufacturing Co., Tulsa

WATER IS THE MOST prevalent impurity produced with oil and gas, and must be removed before the product can be sold. In some cases, as much condensate or oil can be saved by use of a three-phase separator as can be gained by installation of more elaborate equipment.

Basic principles of oil and gas separation have been covered in Part 1 of the Production Practices Manual (WORLD OIL, January 1960). The following discussion will concern the separation of free water and oil.

Free water can be separated from liquid hydrocarbons by retention time and absence of turbulence, without the aid of heat. Also, by definition, free water is not emulsified with another substance.

DESIGN

The three basic types of separators (vertical, horizontal, spherical) may be used for three-phase separation. Regardless of shape, all three-phase vessels must meet the following requirements.

1. Liquid must be separated from gas in a primary separating section.

2. Gas velocity must be lowered to allow liquids to drop out.

3. Gas must be scrubbed through an efficient mist extractor.

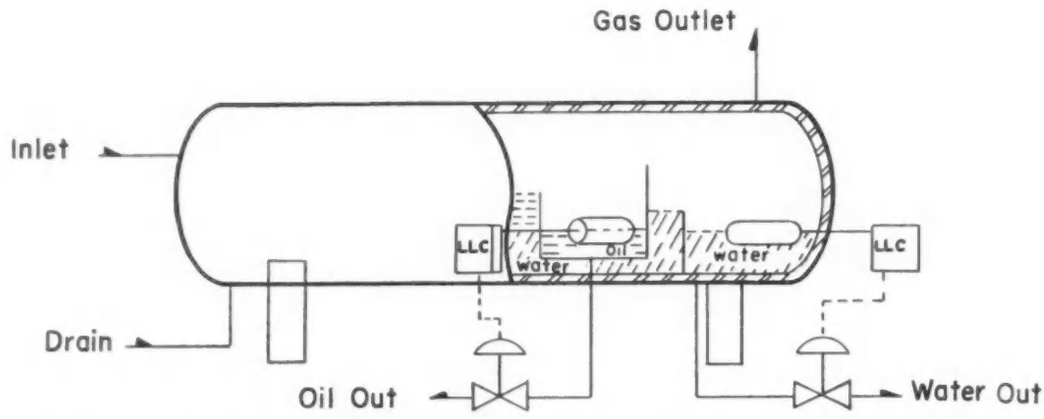


FIGURE 4—Horizontal vessel. Operates in same manner as unit described in Figure 3.

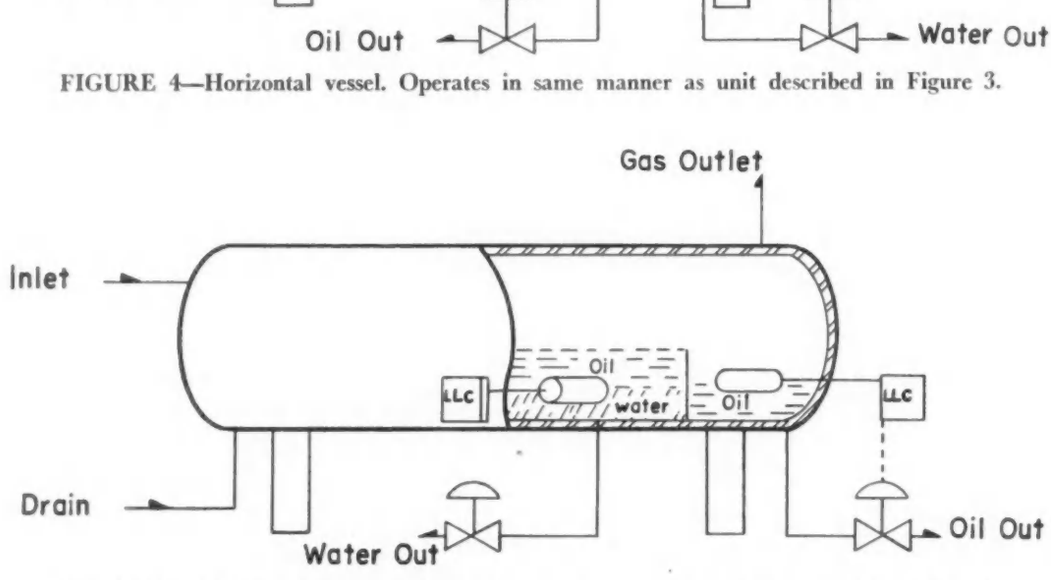


FIGURE 5—Horizontal vessel. Operates in same manner as unit described in Figure 2.

4. Water and oil must be diverted to a turbulence-free section of the vessel.

5. Liquids must be retained in the vessel long enough to allow separation.

6. The water-oil interface must be maintained.

7. Water and oil must be removed from the vessel at their respective outlets.

Control methods. Several control methods are applicable to three-phase separators. The shape and diameter of the vessel will, to a certain degree, determine the type control that can be used. Figures 1-7 show the more generally used methods of three-phasing the basic vessel shapes.

Figure 1 shows a vertical separator three-phased by use of level controls only. The water level control must be of the interfacial type. A displacement type interfacial controller can sense and maintain the interface between the water and oil by controlling the water outlet valve.

Although the method shown in Figure 1 can be used for horizontal and spherical vessels, it is more easily applied to the vertical separator because of the greater thickness of the oil and water columns in the vessel. This permits greater separation of the level control floats and allows the easier-to-operate vertical float installation to be used.

The advantage of this method is simplicity. No internal baffling or weirs are necessary. The relative retention volumes can be varied easily within the interface float length by simply resetting the interface controller. The full liquid volume of the vessel can be utilized as retention volume. This type vessel contains no natural traps which accumulate sand and mud; consequently, the vessel can be easily cleaned through the bottom drain.

The chief disadvantage of this method is that if the water level control or valve should fail, the total volume of oil and water in the vessel will discharge into the water outlet system.

Interfacial control is "touchy" and a prudent and knowledgeable operator is required to make it most effective. It becomes a little more difficult to handle if the top oil level in the vessel is allowed to vary, and because the oil level is controlled by a level controller, there is a slight variance in upper level.

This method has been used effectively and to advantage in many instances.

Figure 2 shows a second method for three-phasing the vertical separator. Figures 5 and 6 show the same method as applied to horizontal and spherical vessels. With this method, the upper oil level is maintained by a weir.

Interfacial control is used to maintain the oil-water interface as described previously. However, in this case total liquid level in the vessel is maintained by a weir and will not vary appreciably. Since the upper level is held constant, the interfacial control is somewhat easier to operate. Interfacial design must be considered carefully, since this

method can possibly waste a good deal of the vessel liquid volume for retention volume (Compare Figures 1 and 2).

The main disadvantage of this method is that internal baffling is required. This makes cleaning the vessel of sediments more difficult. As in the first case relative retention volumes can be varied by use of the interface controller.

Figures 3, 4 and 7 show a third method of three-phasing as applied to vertical, horizontal and spherical separators. This method utilizes a weir to control the top level. Interfacial level in the main body of the separator is set by a water weir.

The water weir may be made adjustable from inside or outside. Inside adjustment would require a shutdown of operation to reset weir height. Outside adjustment requires some type of packing gland in the vessel shell and an internal mechanical linkage to vary weir height. Level controls are used in the separate oil and water sections to control only the levels in those sections.

The advantage of this system is that if level controls or valves fail, only liquid and gas from the affected section will be dumped from the vessel. The main level in the vessel proper will be unaffected and proper three-phase operation can continue. Easy-to-use top level control is used in each section.

Disadvantages include:

1. More internal baffling is required.

2. In all except the sphere, the vessels are difficult to keep clean of sediment.

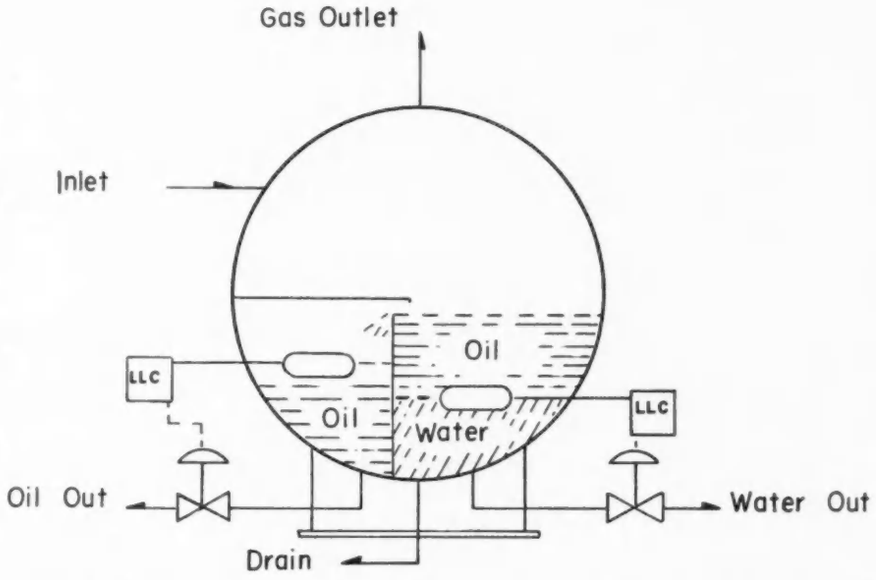


FIGURE 6—Spherical vessel. Operates in same manner as unit described in Figure 2.

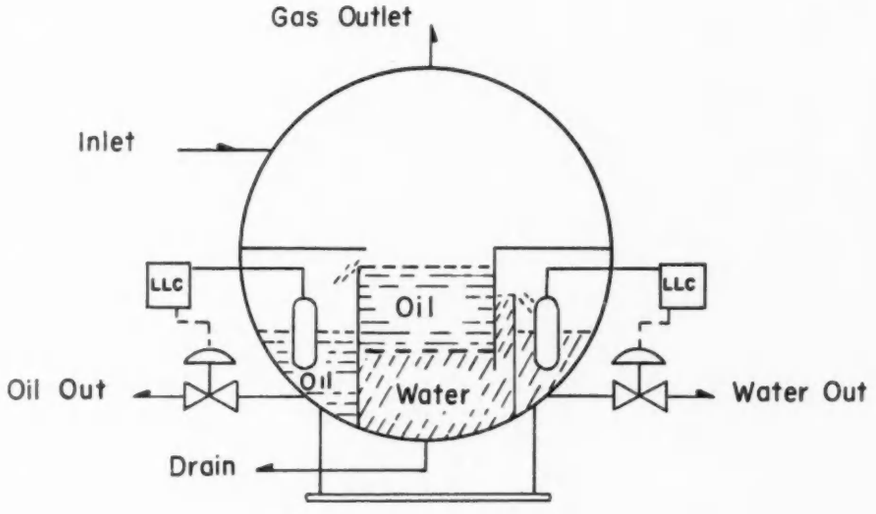


FIGURE 7—Spherical vessel. Operates in same manner as unit described in Figure 3.

3. Some retention volume is wasted when compared to the other two methods.

4. Control of relative retention volumes is more time-consuming in the case of the inside adjustable weir, or more expensive in the case of the outside adjustable system.

SIZING

Sizing a three-phase separator for water removal is a relatively simple problem, since retention time is the only consideration. Retention time is the length of time liquids are allowed to remain in separator. This time is related to volume of the vessel, the amount of liquid to be handled, and the relative specific gravities of the water and oil.

It is important to note that the effective retention volume in a vessel is that portion in which the oil and water remain in contact with one another. Once either substance is separated from the other, although it may remain in the vessel in a separate compartment, the volume thus occupied cannot be considered as a part of the retention volume as far as oil-water separation is concerned. Actually, two retention times may be considered:

1. The period of time oil remains in the vessel to allow adequate separation of water.

2. The period of time water remains in the vessel to allow separation of oil.

The usual approach in design is to allow equal volumes for oil and water in the vessel. For simplicity, the rating charts included in this article were constructed on this basis. In reality, it is good policy to use a vessel design that will allow a variation in the respective volumes devoted to oil and water retention. An interfacial controller or a variable water weir may be used for this purpose.

It is obvious that a given vessel can be divided into any

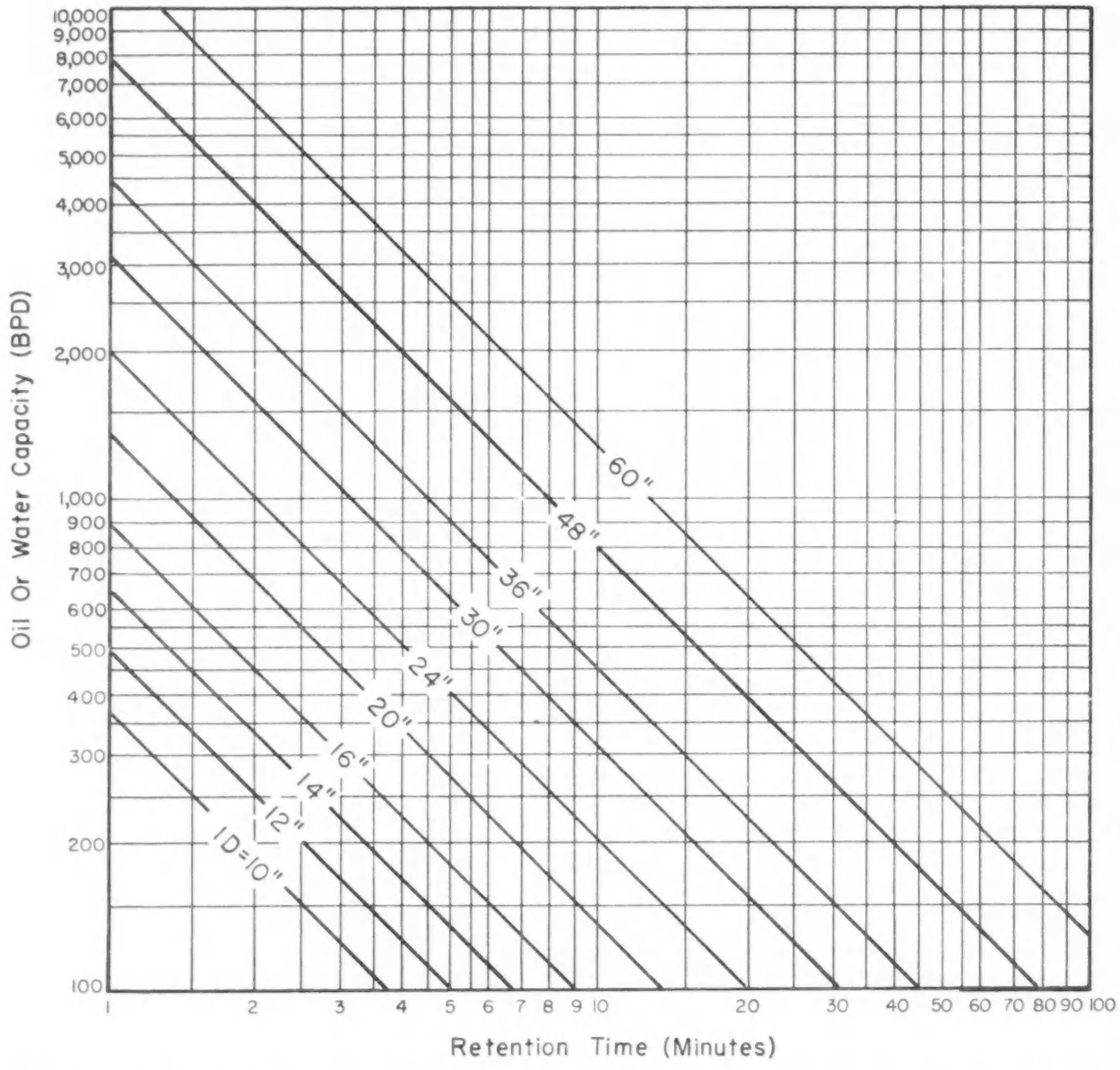


FIGURE 8—Capacity chart for 10-foot shell length single barrel horizontal separators (Basis: ¼ total volume for oil, ¼ total volume for water).

combination of gas, oil and water volumes. However, in most cases the diameter or size of the separator will be governed by the gas volume to be handled. In almost all cases, it is more economical to increase vessel length rather than diameter since a greater shell and head thickness is required when diameter is increased for the same working pressure.

Figures 8, 9 and 10 show oil and water capacities as functions of inside diameter and retention time for single barrel horizontal, vertical and spherical vessels. In constructing these charts, the volume available in the vessel heads was neglected, although in large diameter cylindrical vessels (in excess of 36-42 inches) this head volume would have a considerable effect on capacity. These same curves also can be used for free water knockouts.

Horizontal vessels. Figure 8 is a capacity chart for 10-foot shell length single barrel horizontal separators for various inside diameters. This chart was constructed assuming that one-half of the vessel volume would be used for liquid (so that the gas capacity as determined from Part I of the Manual would not be reduced), and that this volume would be divided equally between the oil and water sections. Also, it was assumed that a method similar to that shown in Figure 1 would be used to maintain top and interfacial levels (the full 10-foot shell length would be used for retention volume).

If a control method similar to that shown in Figure 5 is used, it can be assumed that approximately one foot of shell length is lost to retention volume. Therefore, a vessel designed according to Figure 5 would have approximately 90 percent of the capacity obtained from Figure 8.

If a design similar to Figure 4 is used, it can be assumed that approximately 2½ feet of shell length will be lost to retention volume. In this case, 75 percent of the capacity as obtained from Figure 8 should be used.

Conversely, shell length can be increased to offset losses in volume as shown in Figures 4 and 5. Capacities from Figure 8 are directly proportional to shell length. That is, a 15-foot vessel will have a capacity 1½ times that

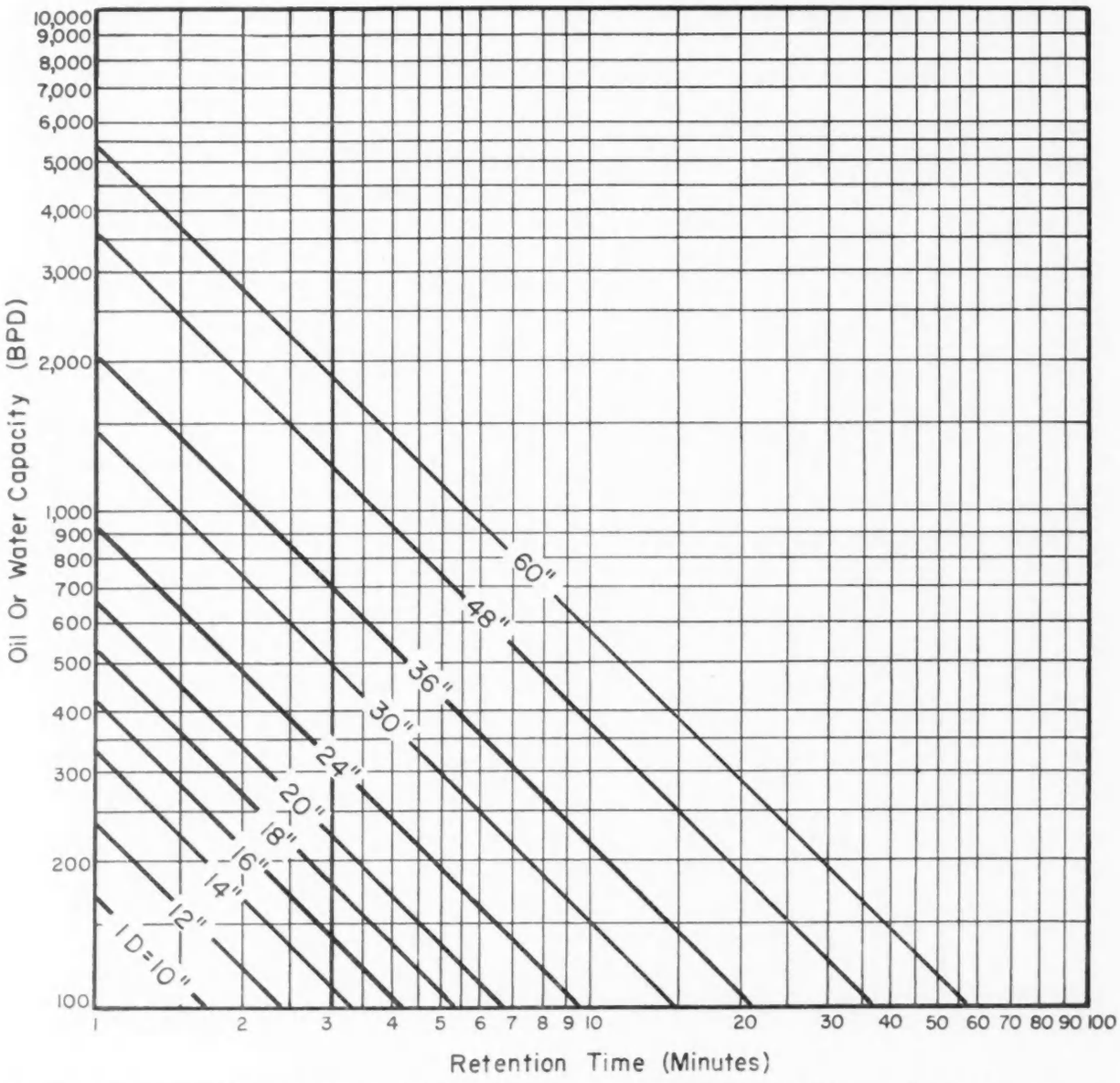


FIGURE 9—Capacity chart for 10-foot shell length vertical separators (Basis: 1.125 feet of oil above interface and 1.125 feet of water between interface and water outlet).

indicated, and a 20-foot vessel will have a capacity twice that determined from Figure 8.

Vertical vessels. Figure 9 is a capacity chart for 10-foot shell length vertical separators of various inside diameters. This chart was developed on the assumption that the vessels would be constructed to contain 1.125 feet of oil column above the interface, and 1.125 feet of water between the interface and the water outlet. These oil and water columns can be used with a 10-foot shell vertical separator (Figure 1) without affecting vessel gas capacity found from Part 1 of the Manual.

If these oil and water columns are used in a 10-foot shell vessel as indicated in Figures 2 and 3, the gas capacity of the vessel would have to be down-rated to that of a standard 5 to 7½-foot shell length vertical separator because of the encroachment into the vessel gas section. If desired, additional shell length could be added to vessels of this type to offset the decrease in vessel volume. If this were done, vessel gas capacity would be rated the same as for a standard 10-foot vertical separator.

Spherical vessels. Figure 10 is a capacity chart for spherical separators of various inside diameters. This chart was constructed assuming that the upper liquid level would be below and not closer than 5-inches from the vessel center line, with one-half of the liquid volume devoted to oil and one-half to water. These oil and water volumes can be used in a spherical vessel with controls designed similar to Figure 1 without affecting the vessel's gas capacity.

If a design similar to Figure 6 is used, 90 percent of the capacity determined from Figure 10 should be used for the vessel's oil and water capacity. If a design similar to Figure 7 is used, capacity should be down-rated to 75 percent of the capacity determined from Figure 10.

Since the capacity charts are based on inside diameter and *not nominal size,* the inside diameter of the vessel should be determined from Figure 6 of Part 1 of the Production Practices Manual (WORLD OIL, January 1960, Page 89).

Use of capacity charts. To use the capacity charts

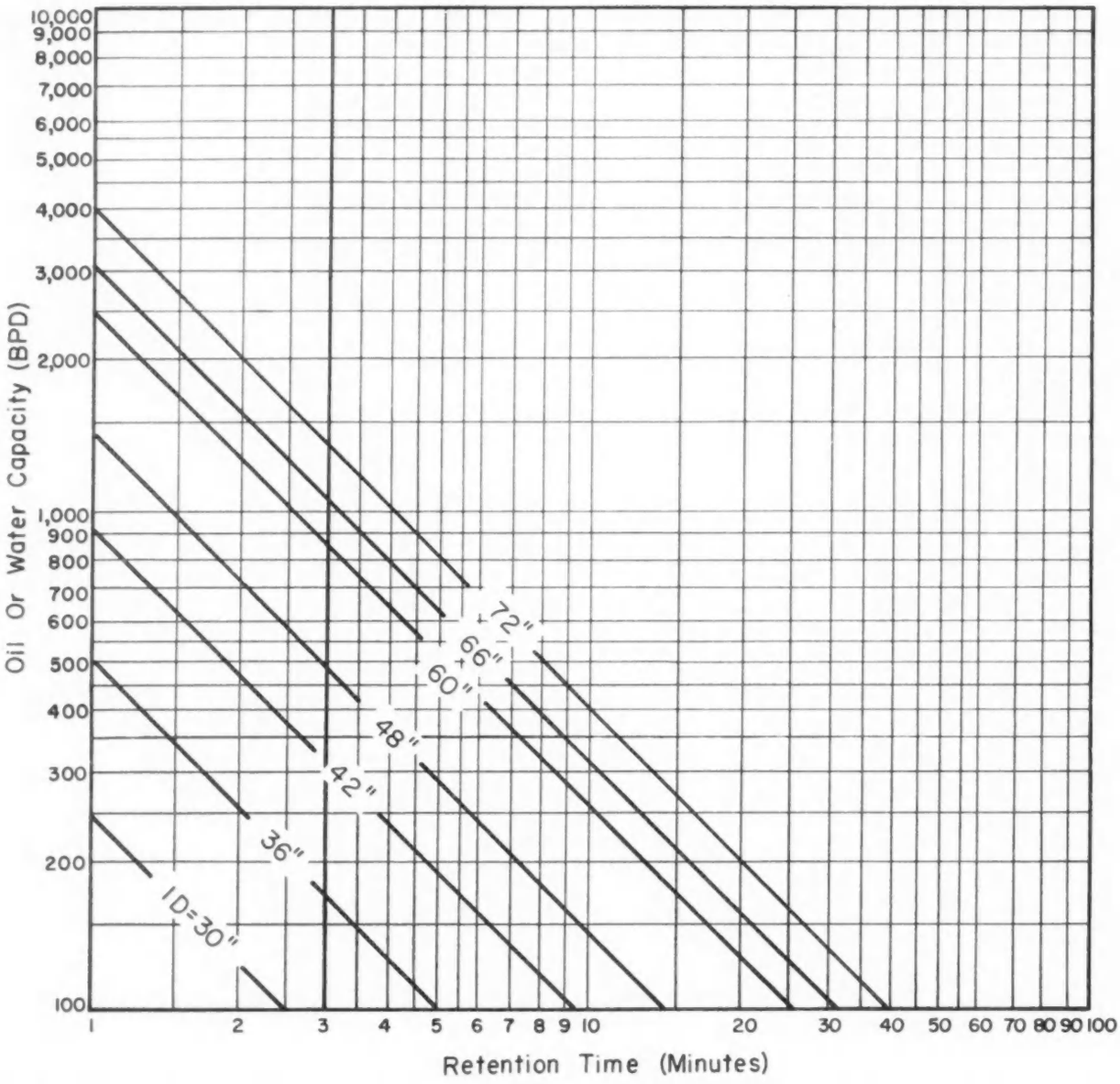


FIGURE 10—Capacity chart for spherical separators (Basis: upper liquid level below and not closer than five inches from center line with ½ liquid volume devoted to oil and ½ to water).

(Figures 8, 9, 10), the inside diameter of the vessel is determined in accordance with the gas volume to be handled. After selecting the proper chart for the vessel shape in question, the intersecting point of the three minutes retention time and the vessel size selected is located. Reading to the left, the maximum amount of water or oil that can be handled for that retention time is determined.

Normally, three minutes retention time will be more than sufficient for separating high gravity oils (50° and higher) and condensates from water. However, additional retention time will be required for lower gravity oils. This can be determined by taking samples and observing separation characteristics after agitation. In some cases the injection of chemicals may be used to decrease retention time.

When ordering a three-phase separator, the purchaser should be able to furnish the manufacturer specific gravities of fluids to be handled. If paraffin or wax conditions are not a consideration, the manufacturer may wish to calculate retention time by a more rigorous method which involves use of these gravities. —**The End**

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Special Report from API meetings

WORLD OIL readers unable to attend the several Mid-Continent regional meetings of the American Petroleum Institute will find the May issue, the API Drilling-Production Special Report, to be designed expressly for them. In it will be the cream of the crop of technical papers given at three 1960 spring meetings: Southwestern (Dallas, March 2-4), Southern (San Antonio, March 16-18), and Mid-Continent (Wichita, March 30-April 1).

It is no secret that drilling contractors and oil producers today are undergoing some painful readjustments in the face of steadily rising costs, reduced allowables and shrinking profits. So it is with this in mind that WORLD OIL's May issue will feature only those carefully selected papers which will have as their one primary objective: Cut costs and increase profits.

We predict this issue of WORLD OIL will be referred to many times; will be a year-long reference for the job-help, cost-cutting type of articles for which WORLD OIL long has been noted.

In addition to the full-length papers, other papers given at the three meetings will be abstracted for your information and convenience.

This is the first time WORLD OIL has scheduled such a comprehensive round-up of API papers. We think you'll agree it will be a value-packed issue. Watch for it.

CORRECTION

Parts C and D of this figure were inadvertently inverted on Page 103 of the March 1960 issue of WORLD OIL. This corrected figure should be substituted for the original which was included in the article "Implosion Technique Improves Fracturing Performance" by Donald D. Setser.

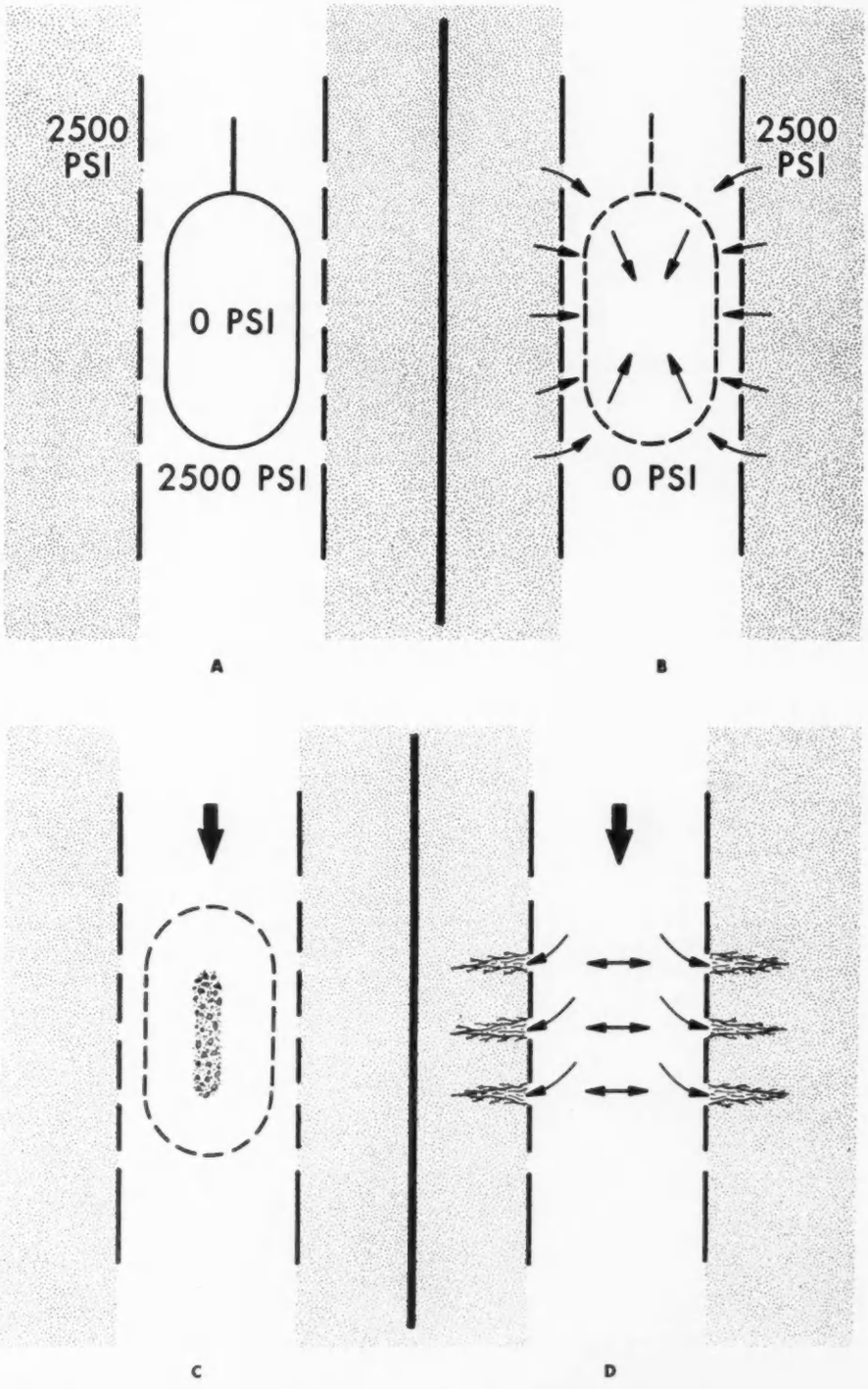
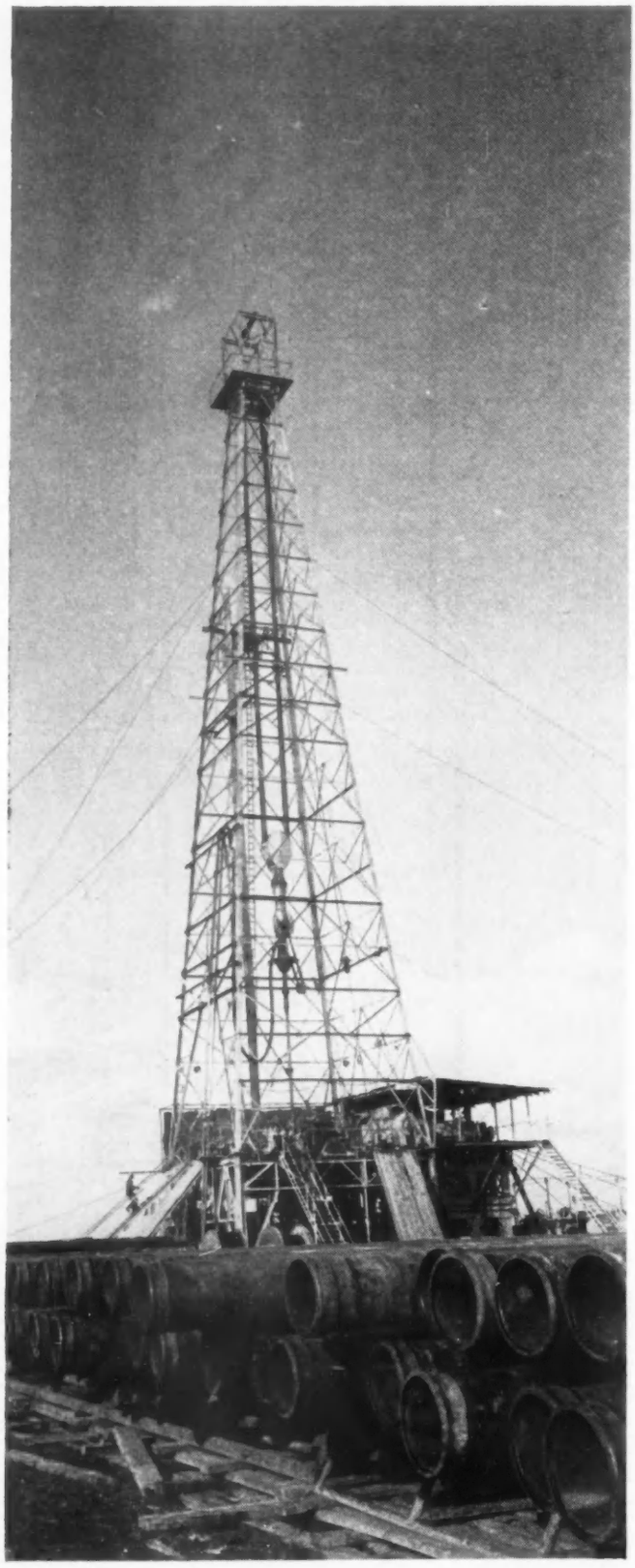


FIGURE 2—This schematic drawing illustrates the implosion technique. In Figure 2A, the hollow cylindrical glass capsule is spotted by wireline or tubing opposite the zone of interest and pump pressure is applied at the surface. In Figure 2B, the collapse pressure of the capsule has been exceeded and the capsule "implodes," drawing fluid into the void space and cleaning the sand face. Figure 2C indicates that the first phase of implosion is about complete and that a high pressure surge produced by the impacting inertial force of the inrushing fluid is about to begin. In Figure 2D, the high pressure surge acts on the formation and initiates fractures. A conventional hydraulic fracture treatment completes the job.

Casing is pulled into the "V" door.



Shown is a portion of the 10,487 feet of 13⅜-inch casing on location ready to be run into the hole.

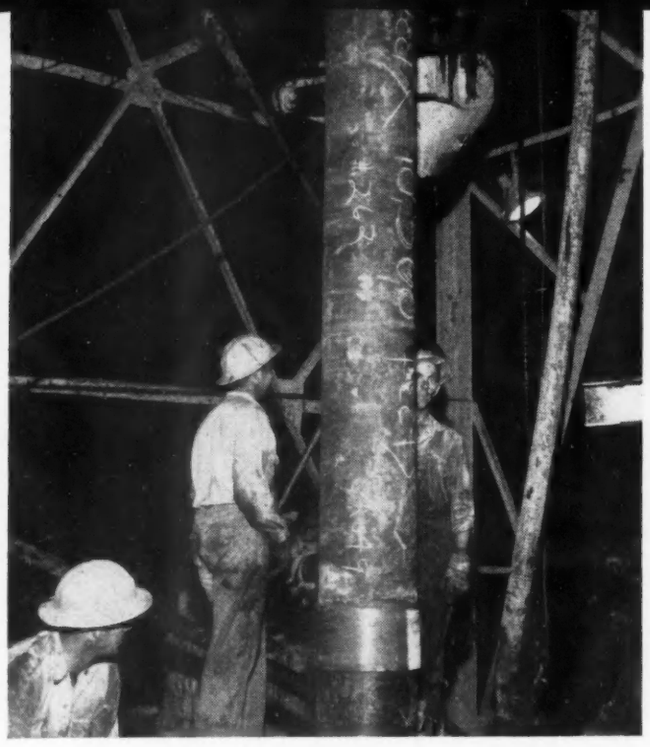
A new record—

Calculated weight of the casing string in the air—756,000 pounds. Maximum weight recorded on the weight indicator—410,000 pounds

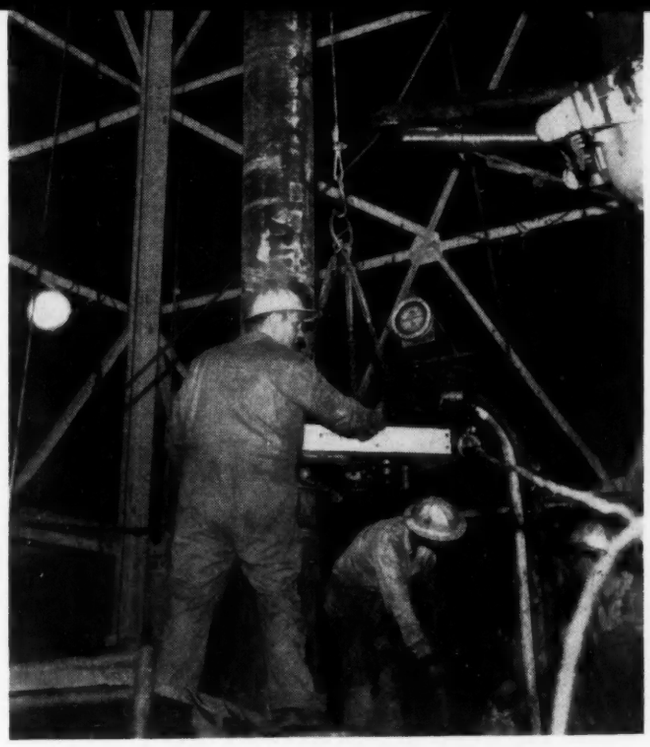
Jack F. Earl, Engineering Editor
World Oil

Union Oil and Gas Corporation of Louisiana and P. R. Rutherford recently set 10,487 feet of 72-pounds-per-foot 13⅜-inch casing. This string was more than 2,000 feet deeper than the previous record depth for 13⅜-inch casing.

The record string was set in the Ursule A. Simon well in the Leleux field south of Crowley, La. (Figure 1). This well was being drilled to a total depth of 18,000 feet to test the Camerina sands of the area including the producing sand of Adams 1 well southwest of the Simon's location. Last August, Adams 1 was completed in the same area with the highest surface pressure recorded—approximately 13,000 psi.



Casing is made up and is ready to run into the hole.



Landing joint, No. 262, final joint of the casing string.

10,487 feet of 13 3/8-inch casing

Due to the experience gained in drilling and completing Adams 1, Union Oil decided that a long string of 13⅜-inch surface casing would be advantageous in the next well. A long string of 13⅜-inch allows subsequent strings of 9⅝-inch and 7-inch to be used to case off deeper formations. The bottom-hole formation pressure of the Simon well was expected to be in excess of 15,000 psi.

Drilling operation. The well was spudded in by Gordan Drilling Company, Inc., on Oct. 6, 1959. A total of 1,508 feet of 20-inch conductor string was set and cemented. A 18½-inch hole then was drilled out to 4,898 feet. From that depth, a 12¼-inch hole was drilled-reamed out to 18½ inches until the depth of 10,487 feet was reached. This is believed to be the deepest 18½-inch hole drilled. The 13⅜-inch casing was run and cemented at this depth.

At no time during the drilling of the 18½-inch hole did it deviate more than ¾ of a degree. The bit weights ranged from 10,000 to 25,000 pounds with rotary speeds of 125-200 rpm.

Mud Program While Drilling 18½-Inch Hole

Depth	Type	Weight	Viscosity	Water Loss
0- 9,000	Low pH (Native)	9.5-10.0	35-40	15-20 cc
9,000-10,000	Gyp-Oil Emulsion	10.5	40-45	6 cc
10,000-10,500	Gyp-Oil Emulsion	11.5	40-45	5 cc
10,500-10,750	Gyp-Oil Emulsion	13.0	45-50	4.5 cc

Running casing string. The protection string consisted of 261 joints of 13⅜-inch, 72 pounds per foot casing calculated to weigh 756,000 pounds in air. The load, reduced by buoyancy, float and friction, did not exceed 410,000 pounds on the weight indicator.

To reduce the weight of the string, the operator floated in 2,000 feet of casing. A tension design factor of 1.98 was attained by considering the buoyant effect of 13⅜-inch casing in 11.5 ppg mud. This design factor was based on 950,000 pounds minimum ultimate joint strength of 72 pound S-80 casing.

The derrick was strung with twelve 1⅜-inch lines. The maximum weight recorded on the weight indicator was 410,000 pounds. The running of the casing required 11½ hours.

Of the 88 straight guide latch-on centralizers, one was spaced at the float shoe at 10,485 feet, one at 10,442 feet and 86 on approximately 120-feet centers.

Cementing operation. The casing was cemented with 4,750 sacks of common cement with 10 percent gel and 118,750 pounds of gilsonite containing 0.9 percent retarder followed by 200 sacks of neat cement. Cement returns were obtained for a period of 4 minutes. Maximum pumping pressure reached was 1,200 psi. Two hours and 20 minutes were required to mix and pump down cement.

The casing operation was successful because of advance planning and drilling techniques. The information gained from operating and drilling the Adams well proved in-

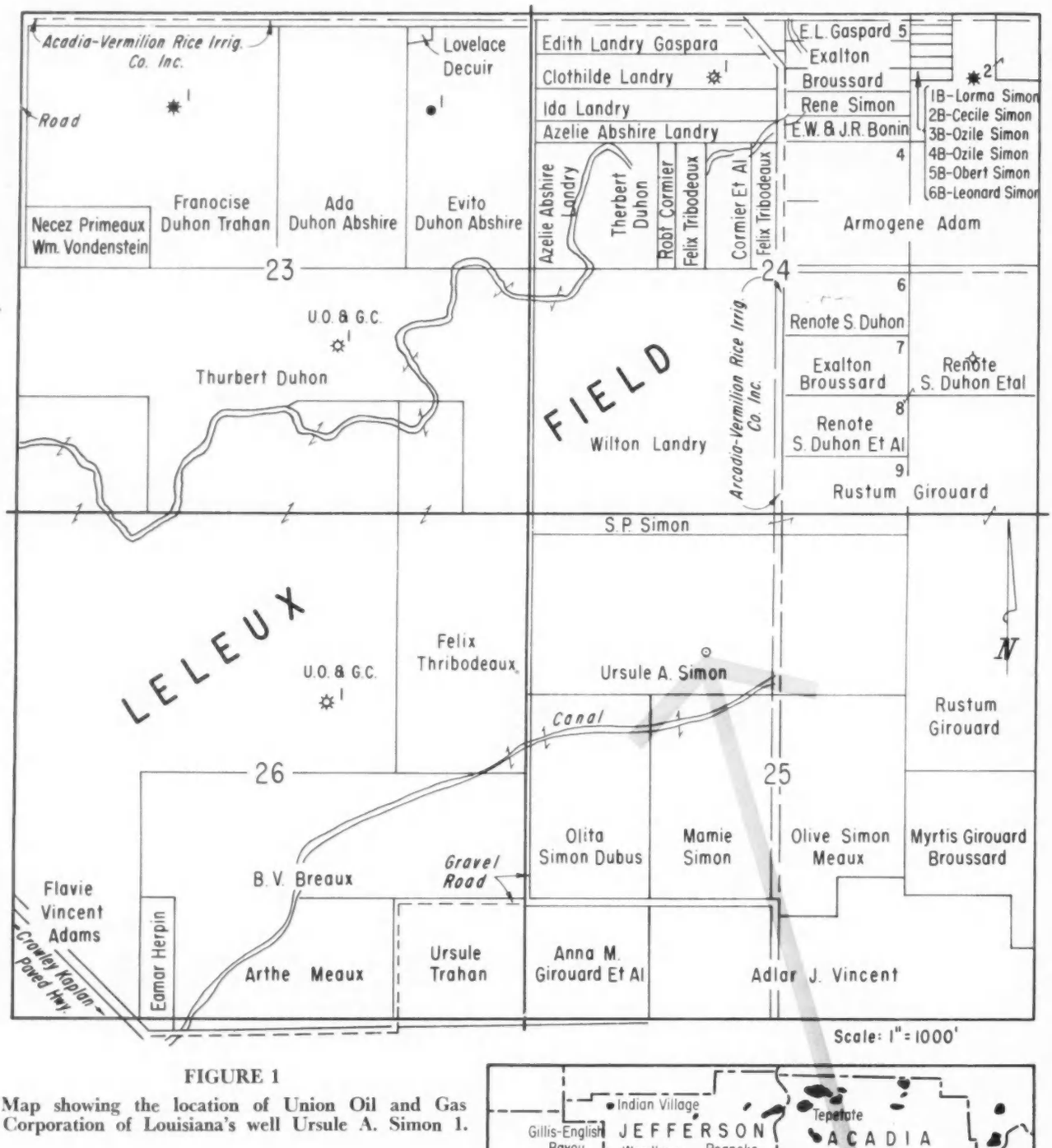


FIGURE 1

Map showing the location of Union Oil and Gas Corporation of Louisiana's well Ursule A. Simon 1.

valuable in the over-all drilling program for the Simons well.

Casing program. Following the setting of the 13⅜-inch casing, a 12¼-inch hole was being drilled to approximately 12,000 feet where it was planned to set a full string of 9⅝-inch casing. An 8½-inch hole then was scheduled to be drilled to a point where pressures require setting 7-inch casing. It was anticipated that a 6-inch hole could be drilled on to the 18,000 feet objective depth and cased with 4½-inch liner. —**The End**

Here's how an artificial lift study can save you money

Accurate operating cost data, good reservoir predictions are required for best results

By Robert W. Drake, Jr., District Engineer
The Atlantic Refining Co., Odessa, Texas

A THOROUGH STUDY of the various types of artificial lift conducted prior to installing pumping or gas lift equipment in the first well on a lease which requires lift, may save an operator thousands of dollars during the productive life of the lease.

There are always two or more methods by which any oil well can be artificially lifted. The mistaken idea that there is only one method of lift for all wells can prove costly for an operator. Too often, one or more methods are disregarded because of prejudice, ignorance, or fear of new or unfamiliar types of lift.

When an oil well first requires lift, any type will show a quick payout; however, a comprehensive study may result in thousands of dollars saved during its productive life. As it becomes necessary to "pump" from greater depths, proper lift selection becomes more valuable.

The engineer has two goals in the selection of artificial lift equipment. His primary purpose is to select equipment which will deplete the well. A second aim is to select the type lift which will result in the most economic depletion. The type with the lowest first cost is not necessarily the cheapest type to depletion. In general, a lift study should be confined to one phase of depletion; that is, it is usually not possible to include secondary recovery lift in a primary lift study. At the time of primary lift, secondary recovery method and performance is seldom known.

Any artificial lift study must be based on well and reservoir characteristics. The better the reservoir predictions are, the better the lift study.

Requirements. Assume the first well on a lease requires lift. For a proper evaluation of artificial lift methods, the following information should be known or predictable:

1. Number of wells expected.
2. Reservoir data.
   a. Bottom-hole pressure and productivity index.
   b. Oil and water production.
   c. Gas/oil ratio.
3. Availability and cost of high pressure gas and electricity.
4. Operating costs of various types of lift.
5. Equipment life.
6. Surplus equipment.
7. Consolidation or commingling possibility.

Often, some of this information is sketchy or not available. However, in most instances enough data can be gathered to permit selection of the most economical type lift.

This article is not intended to cover design of individual artificial lift installations since ample data for this purpose is available in the literature. However, the engineer must keep reservoir characteristics and predictions in mind.

For example, an 8,500 foot well in a solution gas reser-

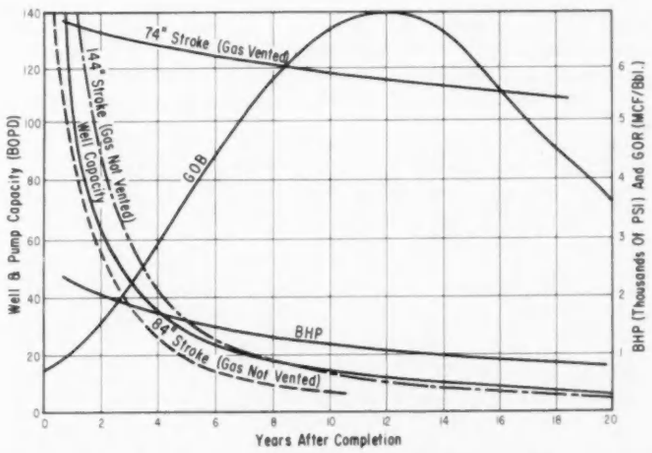


FIGURE 1—Gas interference can play an important role in the selection of a pumping unit. In this case, a 74-inch stroke unit is sufficient to deplete the well if gas is vented. If gas must be "pumped," a 144-inch unit is required.

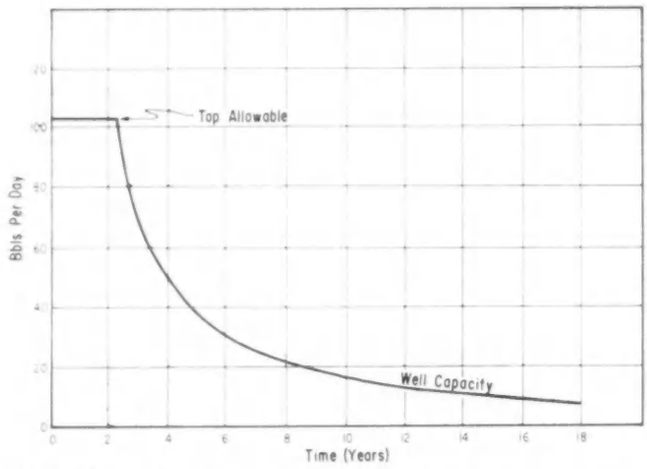


FIGURE 2—Example problems of lift selection presented herein are based on wells which exhibit this type decline curve.

voir requires lift. A beam pumping installation is designed to lift the allowable from total depth without thought of bottom-hole pressure, productivity index or decline in productivity. The unit installed is capable of pumping 150 bpd from 8,500 feet, yet, by the time it is necessary to lift from this depth, the well capacity has declined to 30 bpd. By matching the pumping unit with well characteristics, it is often possible to use a smaller size unit.

Conversely, disregard of gas fluid ratio where gas must pass through the pump may result in installation of a 7 foot stroke unit where a 12 to 20 foot stroke is required. For example, 1,000 scf of 0.9 gravity gas at reservoir conditions of 200° F and 500 psi occupies 5.85 barrels of space at the pump. Thus, if the gas/oil ratio is 1,000/1, a volume of 6.85 barrels will have to be pumped to produce one barrel of oil. Figure 1 shows the effect of gas interference. In this example, a 74 inch stroke unit will deplete the well if gas is vented. If gas must be "pumped," a 144 inch stroke is required.

TABLE 1—Calculation of operating costs for 6,000-foot well (Case 1) with capacity as shown in Figure 2 plus 25 percent water.

YEAR	Present Worth Factor (8%)	Present Worth Operating Costs				
		Rod Pump ($)	Hydraulic Pump ($)	Gas Lift		
				O.P. Cost ($)	Gas Cost ($)	Total ($)
1	.9610	1730	1960	1384	4652	6036
2	.8872	1597	1810	1278	3033	4311
3	.8189	1474	1671	1179	2008	3187
4	.7560	1361	1542	1089	1424	2513
5	.6979	1256	1424	1005	1075	2080
6	.6442	1160	1314	928	804	1732
7	.5947	1070	1213	856	668	1524
8	.5490	988	1120	791	529	1320
9	.5068	912	1034	730	435	1165
10	.4678	842	954	674	373	1047
11	.4318	777	881	622	320	942
12	.3986	717	813	574	272	846
13	.3680	662	751	530	230	760
14	.3397	611	693	489	194	683
15	.3136	564	640	452	160	612
16	.2895	521	591	417	116	533
17	.2672	481	545	385	92	477
18	.2467	444	503	355	71	426
Totals	.....	17,167	19,459	13,738 + 16,456 = 30,194		

TABLE 2—Calculation of operating costs for 8,500-foot well (Case 2) with capacity as shown in Figure 2, no water.

YEAR	Present Worth Factor (8%)	Present Worth Operating Costs				
		Rod Pump ($)	Hydraulic Pump ($)	Gas Lift		
				O.P. Cost ($)	Gas Cost ($)	Total ($)
1	.9610	1960	2306	1442	4469	5911
2	.8872	1810	2129	1330	2914	4244
3	.8189	1671	1965	1228	1929	3157
4	.7560	1542	1814	1134	1368	2502
5	.6979	1424	1675	1047	1033	2080
6	.6442	1314	1546	966	773	1739
7	.5947	1213	1427	892	642	1534
8	.5490	1120	1318	824	508	1332
9	.5068	1034	1216	760	418	1178
10	.4678	954	1123	701	358	1059
11	.4318	881	1036	648	307	955
12	.3986	813	957	598	261	859
13	.3680	751	883	552	221	773
14	.3397	693	815	510	186	696
15	.3136	640	753	470	154	624
16	.2895	591	695	434	111	545
17	.2672	545	641	401	88	489
18	.2467	503	592	370	68	438
Totals	.....	19,459	22,891	14,307 + 15,808 = 30,115		

Costs. Since an operator is interested in depleting a well or wells for the lowest total cost, accurate cost data—initial, replacement and operating—are required. Initial costs for all types of equipment are easily obtained. Replacement costs vary according to productive life of the well and life of various components, but if proper records have been maintained, these costs are readily determined.

Operating costs are sometimes difficult to compute. This is particularly true for a type lift with which an operator has had little or no operating experience. Published data from trade journals, technical papers and manufacturers' brochures are helpful in estimating such costs. Also, other operators are usually willing to relate their experiences with various types of lift. This is not to say that lifting costs will be made available; however, most operators will reveal information such as average pump runs, input GOR and difficulties with various types of lift. This information, coupled with knowledge of company work policy (pumper work load, salary, benefits, etc.), should permit determination of reasonably accurate operating costs.

Operating costs usually are expressed in cents per barrel. For an economic comparison over an extended period, these costs are better expressed in dollars per well per month, or dollars per well per year. This is because most operating costs are fixed and do not decline with production.

For example, it takes about the same personnel and equipment to operate the same depth well whether it produces 100 bpd or 10 bpd. In fact, due to inherent difficulties in operating a "stripper," costs may go up. This fact is often overlooked by top management. The exception to the general rule is gas lift. Here the volume of lift gas (a significant cost item) may or may not decline as production declines. In a solution gas drive reservoir,

About the Author

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lift gas volume should decline; in a water drive reservoir, lift gas volume will increase.

Salvage value of equipment must be considered. In general, only major long-lived items have an appreciable salvage value. Depreciation policy varies with different operators, but straight line depreciation where equipment is assigned a "life expectancy" and depreciated uniformly over this period is probably the most common method now in use. Relatively small items (bottom-hole pumps, sucker rods, gas lift valves) usually have no appreciable salvage value.

After all costs have been calculated, an economic comparison may be made. It is theoretically possible to deplete a well with no initial investment, but with excessive operating costs; that is, by continuous swabbing. It also might be possible to install some type lift, at a great initial cost, that would have no operating cost.

To select the most economical type lift, some method must be used to place the initial and operating costs in their proper perspective. The most equitable method is the present worth basis. Here, future costs and salvage values are discounted back to the time of initial investment. The interest rate used in discounting will vary with different operators and as cost of capital varies. A fair range today is between six to ten percent.

To demonstrate this type analysis, arbitrary initial and operating costs will be assumed for various type lifts for two depths. These values are assumed for illustration only.

BASIC ASSUMPTIONS

1. Capacity as shown in Figure 2.
2. Eighteen-year pumping life.
3. Pumping unit life—30 years.
4. Triplex life—25 years.
5. Gas engine life—6 years.
6. Eight percent interest rate.
7. Lift gas cost—5¢ per Mcf.

Case 1—6,000 foot well. (Capacity as shown in Figure 2 plus 25 percent water).

1. Initial costs
   a. Rod pump—$12,500 per well
   b. Hydraulic pump—
      1 well—$16,000 per well
      2 wells—$13,000 per well
      4 wells—$10,000 per well
   c. Gas lift—$4,000 per well
2. Operating costs
   a. Rod pump—$150 per well per month
   b. Hydraulic pump—$170 per well per month
   c. Gas lift—$120 per well per month plus cost of lift gas
   d. Input GOR—2,500 cubic feet per barrel.

Using these values, operating costs are calculated as shown in Table 1.

Initial, replacement and salvage values are calculated as follows:

Year	Item	P.W. Factor	Rod Pump 1 Well	HYDRAULIC PUMP 1 Well	HYDRAULIC PUMP 2 Wells	HYDRAULIC PUMP 4 Wells	Gas Lift
0	Initial	1.0000	$12,500	$16,000	$26,000	$40,000	$4,000
7	Replace Engine	.5947	714	714	1,189	1,784	....
13	Replace Engine	.3680	442	442	736	1,114	....
Total Investment			13,656	17,156	27,925	42,898	4,000
Less Salvage			—444	—136	—308	—308	....
Net Cost per well			**$13,212**	**$17,020**	**$27,617**	**$42,590**	**$4,000**

Salvage Value Calculations

Pumping unit original cost	$5,000 (30-year life)
Depreciation $\frac{\$5,000}{30}$ x 18	—3,000
	$2,000
Cost to salvage	— 200
	$1,800
P.W. Value (0.2467 x 1,800)	$ 444
1 well Triplex original cost	$2,500 (25-year life)
Depreciation $\frac{\$2,500}{25}$ x 18	—1,800
	$ 700
Cost to salvage	— 150
	$ 550
P.W. Salvage (0.2467 x 550)	$ 136
2—4 well Triplex original cost	$5,000 (25-year life)
Depreciation $\frac{\$5,000}{25}$ x 18	—3,600
	$1,400
Cost to salvage	— 150
	$1,250
P.W. Salvage (0.2467 x 1,250)	$ 308

The present worth values for equipment and operating costs then are combined to find over-all costs.

	Rod Pump	HYDRAULIC PUMP 1 Well	HYDRAULIC PUMP 2 Wells	HYDRAULIC PUMP 4 Wells	Gas Lift
P.W. Equipment Cost per well	$13,212	$17,020	$13,808	$10,647	$ 4,000
P.W. Operating Cost per well	17,167	19,459	19,459	19,459	30,194
Total P.W. Costs	**$30,379**	**$36,479**	**$33,267**	**$30,106**	**$34,194**

Based on this comparison, rod pumping equipment would be selected and installed if the lease has fewer than 4 wells. Hydraulic pumping equipment is indicated for use on multiple well (more than four) leases.

Case 2—8,500 foot well. (Capacity as shown in Figure 2—no water).

1. Initial costs
   a. Rod pump—$20,000 per well
   b. Hydraulic pump
      1 well—$18,000 per well
      2 wells—$15,000 per well
      4 wells—$12,000 per well

c. Gas lift—$4,500 per well

2. Operating costs

a. Rod pump—$170 per well per month

b. Hydraulic pump—$200 per well per month

c. Gas lift—$125 per well per month plus cost of gas

d. Input GOR—3,000 cubic feet per barrel.

Operating costs then are calculated as shown in Table 2.

Initial, replacement and salvage values are calculated as tabulated below:

Year	Item	P.W. Factor	Rod Pump 1 Well	HYDRAULIC PUMP 1 Well	HYDRAULIC PUMP 2 Wells	HYDRAULIC PUMP 4 Wells	Gas Lift
0	Initial	1.0000	$20,000	$18,000	$30,000	$48,000	$4,500
7	Replace Engine	.5947	892	892	1,487	2,081	.....
13	Replace Engine	.3680	552	552	920	1,288	.....
Total Investment			21,444	19,444	32,407	51,369	4,500
Less Salvage			—819	—136	—308	—308	.....
Net Cost per well			**$20,625**	**$19,308**	**$15,050**	**$12,515**	**$4,500**

Salvage Value Calculations

Pumping unit original cost	$8,800 (30-year life)
Depreciation $\frac{\$8,800}{30} \times 18$	—5,280
	$3,520
Cost to salvage	— 200
	$3,320
P.W. Salvage Value (0.2467 x 3,320)	$ 819
1 well Triplex original cost	$2,500 (25-year life)
Depreciation $\frac{\$2,500}{25} \times 18$	—1,800
	$ 700
Cost to salvage	— 150
	$ 550
P.W. Salvage (0.2467 x 550)	$ 136
2—4 well Triplex original cost	$5,000 (25-year life)
Depreciation $\frac{\$5,000}{25} \times 18$	—3,600
	$1,400
Cost to salvage	— 150
	$1,250
P.W. Salvage (0.2467 x 1,250)	$ 308

The present worth values for equipment and operating costs then are combined to find over-all costs.

	Rod Pump	HYDRAULIC PUMP 1 Well	HYDRAULIC PUMP 2 Wells	HYDRAULIC PUMP 4 Wells	Gas Lift
P.W. Equipment Cost per Well	$20,625	$19,308	$15,050	$12,415	$ 4,500
P.W. Operating Cost per Well	19,459	22,891	22,891	22,891	30,115
Total P.W. Costs	**$40,184**	**$42,199**	**$37,941**	**$35,306**	**$34,615**

Based on this comparison, lift selection would be as follows:

1. Lift wells by gas lift if gas available at 5¢ per Mcf.

2. If high pressure gas not available,

a. Lift 1 well lease with rod pump

b. Lift 2 to 4 well lease with hydraulic pump.

Additional considerations. The final lift selection for either case will be made after taking into account the following factors:

1. Surplus equipment that may be used

2. Possibility of consolidation and/or commingling

3. Time lapse between initial and subsequent well installations on multiple well leases.

It is apparent that surplus material will materially change the final lift selection. Also, a long time lapse between first and latter lift requirements on multiple well leases will require discounting future individual well costs back to time of initial installation. For example, the central plant, a major cost item in hydraulic pumping, must be installed when the first well requires lift.

Examination of results of the two cases analyzed emphasizes the importance of two factors: reservoir predictions and operating cost data. Reservoir predictions are particularly important for gas lift operations. In rod and hydraulic pumping, 25 to 50 percent water production will not materially change the monthly per well cost. In gas lift, however, this much water production will make a great difference.

Some further generalizations concerning types of lift may also be drawn from the cases studied. These are briefly summarized by type lift as follows:

1. Rod pumping—On deep wells (below 8,500 feet) initial cost per well is relatively high.

2. Hydraulic pumping—On medium and shallow wells, initial cost per well is relatively high for a few well lease.

3. Gas lift—Initial cost per well for any depth is relatively low. However, operating cost can be relatively high.

The examples covered in the two cases were for singly completed wells with specified conditions. Dual wells and/or water drive wells will present a different set of conditions. In these wells, methods of lift should include dual pumps and submergible electric pumps; however, the method would be the same.

This selection method may seem unnecessary to many; however, with deeper pumping and long reservoir life, significant savings may be possible.

This article is an expanded version of a paper which was presented to the Sixth Annual West Texas Oil Lifting Short Course in Lubbock, Texas. —**The End**

here's a thorough . . .

Geologic evaluation of aerated water-drilled wells

Oil and gas shows, good cuttings, derrick floor drilling data readily evaluated at wellsite

By Paul L. Gassett
Staff Engineer—Drilling
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GULF OIL CORPORATION's experience with aerated water drilling shows that wellsite geologists and drilling engineers can work together very effectively to provide good geological evaluation without departing radically from conventional procedures. However, many considerations need to be borne in mind so that this relatively new drilling method can be employed with maximum effectiveness, particularly on wildcat wells. Some of the salient points in this regard follow:

- Oil and gas shows are readily detected
- Wellsite geologists need to be cognizant of the buoyancy effects of aerated water on the drill pipe to prevent adoption of erroneous conclusions concerning changes in drilling rates. Close observance of derrick floor drilling conditions should also be made by geologists to avoid errors in sample logs
- Cuttings resulting from uphole erosion must be distinguished from those circulating from the bottom. This distinction is readily made. As the depth increases, the percentage of uphole material tends to increase also
- Although cuttings from shallow or moderate depth aerated water drilled holes are usually about the same size as those from conventional mud drilling, aerated water drilled cuttings may be smaller in deep, cased holes or where long sections of hard formations have been cut. In shallow drilling —5,000 to 7,500 feet—cuttings are generally large enough to be useful to micropaleontologists. In deeper drilling, cuttings may be too small to provide a good fossil sequence, and coring may be required to maintain it.
- Cuttings have a tendency to slow down in cavities drilled at great depths
- Occasionally, individual formation fragments as heavy as six pounds are blown out of shallow aerated water drilled holes
- Aerated water drilled wells tend to load up and flow off, impairing the continuity of samples. Manipulation of the air/fluid ratio and other operating characteristics by the drilling engineer can improve this condition.
- Swelling clays are very difficult to identify.

HOW AERATED WATER DRILLING DEVELOPED

Aerated water or aerated mud drilling is generally performed with the thought of reducing costs. Aerated fluid drilling's greatest field probably is in an area of considerable lost circulation, cavernous or hard formations, or water shortage. This technique was employed in British Honduras exploratory drilling to overcome lost circulation in cavernous limestone and dolomite; offshore in the Key West,

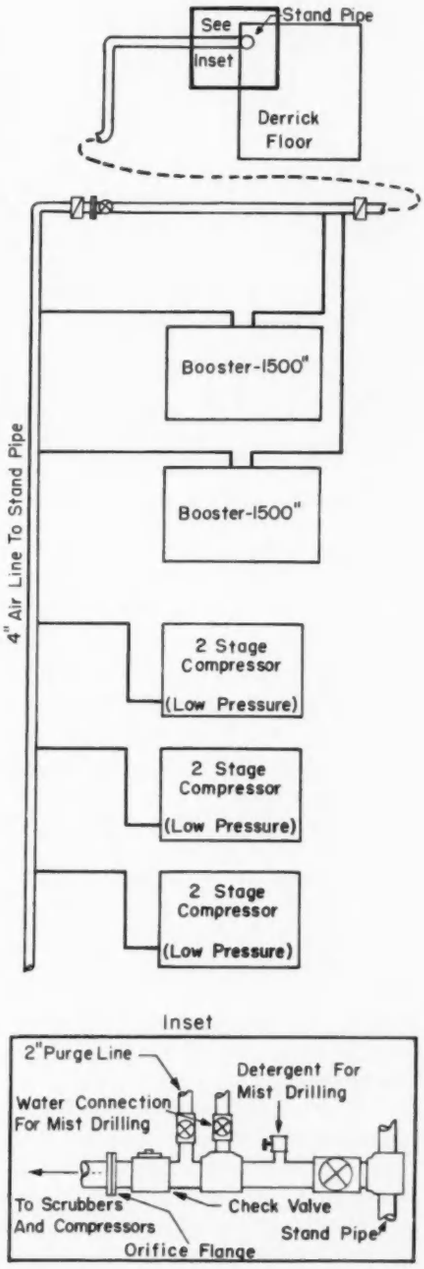

FIGURE 1—This schematic diagram shows the general layout of compressors and connections for air, gas, mist, or aerated fluid drilling.

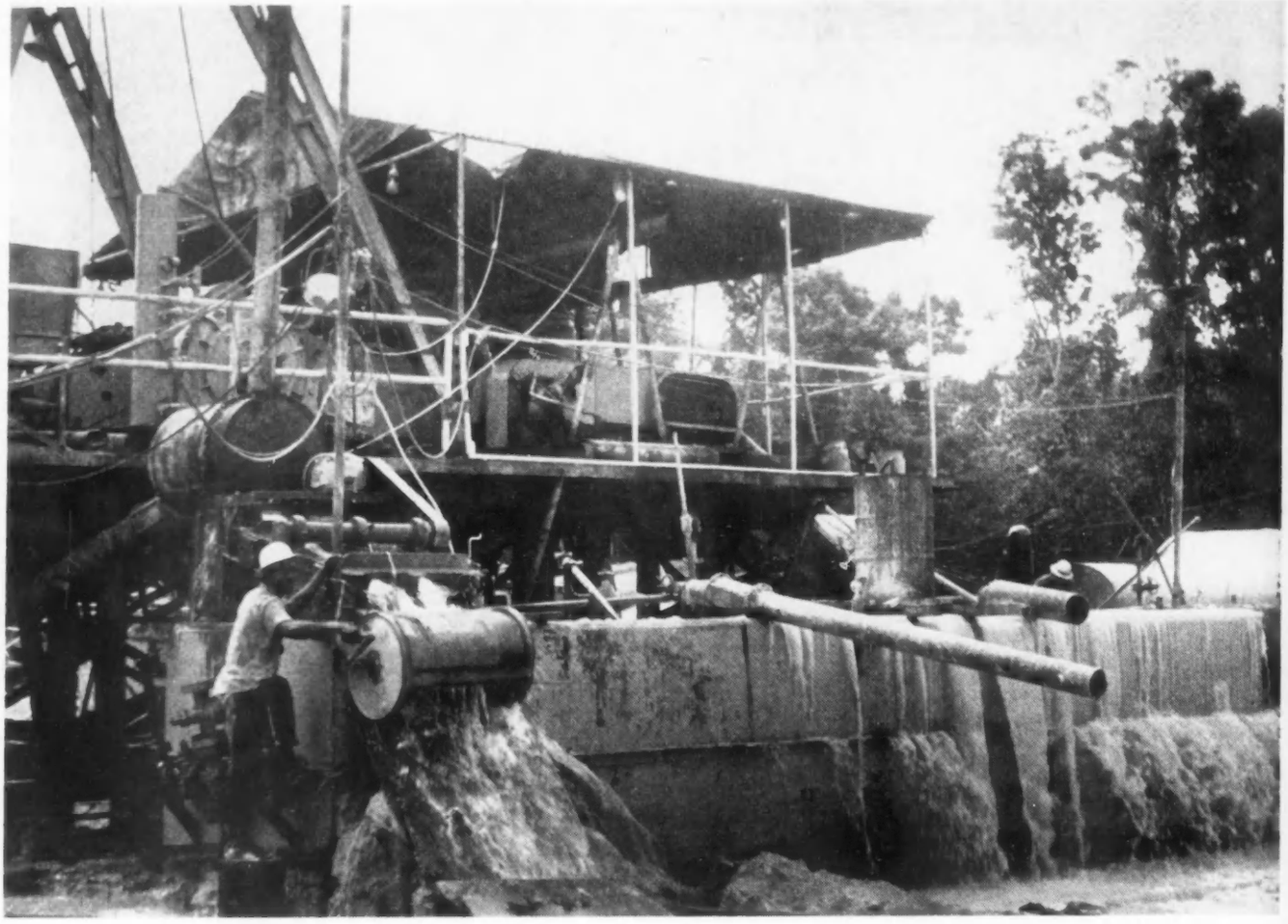

FIGURE 2—This photograph shows the aerated water return at the shale shaker on British Honduras Gulf Oil Company Tower Hill 2 wildcat. Water overflows the pit and shale shaker. A samples catcher was devised, using a 20-by-20 mesh shale shaker screen and an oil drum. Sections of the drum were cut out for water penetration of the screen and entrapment of samples. Excess samples could be dumped by rotating drum. Water flow rate was measured at 3,000 barrels an hour.

Fla., area to overcome lost circulation; and in West Texas wildcats to penetrate hard quartzite and to speed the drilling rate in general. The method was employed in North Africa to overcome water shortage, lost circulation, and to speed the penetration rate in exploration drilling.

Success in some areas has been phenomenal. In some areas the economics were about the same as conventional mud drilling. In every case the penetration rate increased. More attention by drilling engineers is required when employing aerated fluid drilling.

When air and gas drilling developed in the search for oil, it was found that water production by the formations penetrated was the greatest disadvantage. Originally it was the custom to convert to conventional mud drilling when water was encountered. Later mist drilling was developed to handle small amounts of water; this was later expanded to include water production rates of about 60 barrels per hour, depending on such things as type of water produced, water disposal problems, increased penetration rates over mud drilling, and the economics of this type of drilling in general as compared to mud drilling.

Experience gained in mist drilling showed that penetration rates were slower than air drilling, but generally much greater than conventional mud drilling. Air was then added to the drilling fluid (Figure 1) to lighten the column of fluid returning in the annulus and in turn to lower the hydrostatic head on the formation. This in turn accounts partially for the increased drilling rate.

It was soon found that aerated fluid penetration rate was considerably faster than mud drilling. Actually the rate was found to be greater than would be expected by the reduced hydrostatic head caused by injecting the air. This might be attributed to turbulence set up in the bottom of the hole as the air-laden drilling fluid passes through the rock bit. This turbulence might sweep the hole clean or it might prevent sealing of formation fractures caused by the bit teeth as the bit rotates.

It is generally found that if air is added to a fluid circulating system the penetration rate will increase considerably when the air-laden fluid passes through the bit. In several cases tests have been run during drilling at about 10,000 feet in wells which filled with fluid on trips and during other down time. It was found that as soon as air passes through the bit the drilling rate would increase, while other drilling characteristics such as weight on bit, kelly rotation rate, and circulating rate remained constant. The penetration rate would then continue to increase and would reach a maximum rate after the hole was unloaded and

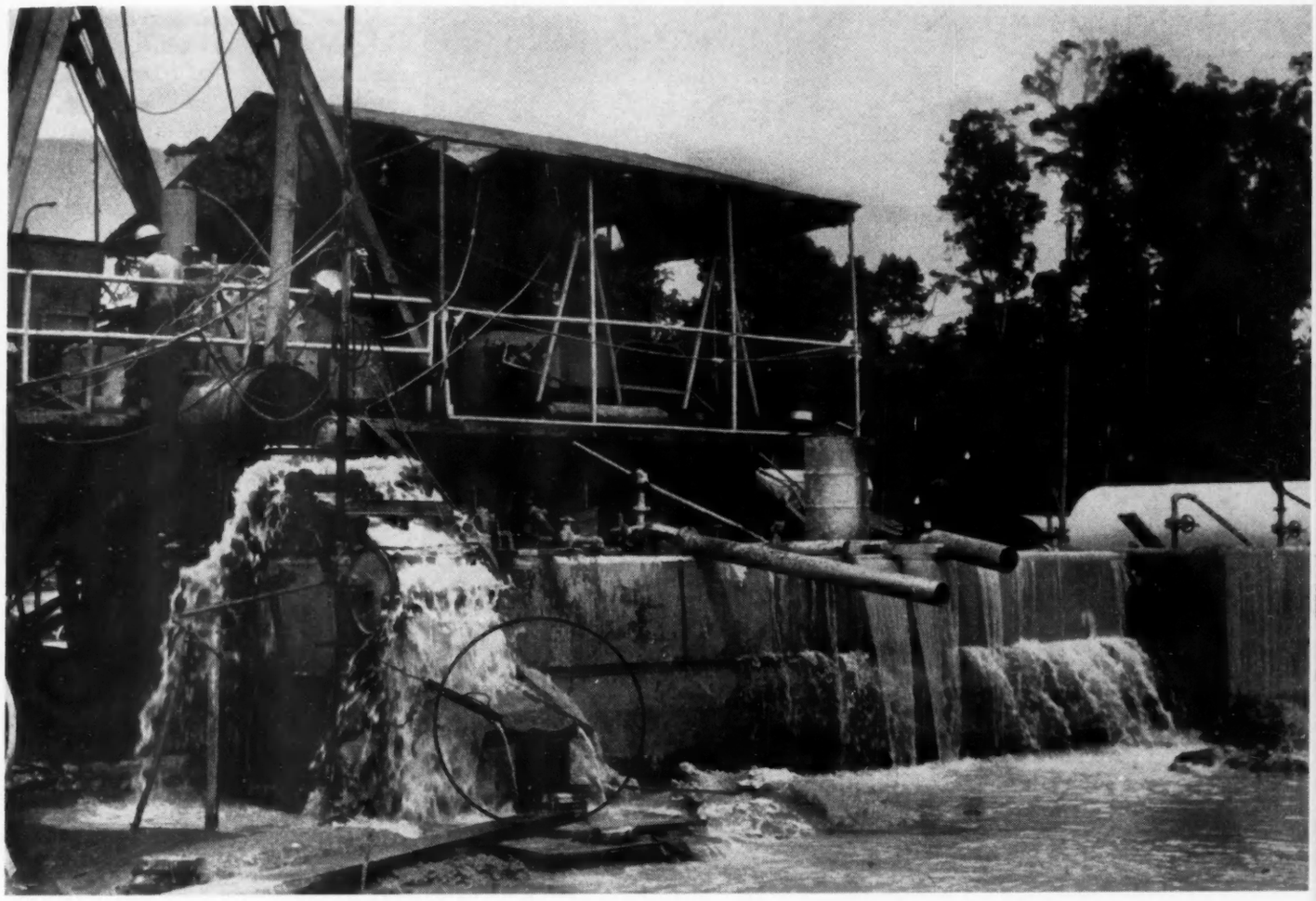

FIGURE 3—Experimentation showed that better samples could be obtained by placing a second shale shaker screen to catch the overflow from the vibrating screen. This photograph was also taken at the Tower Hill 2 location in British Honduras, and shows a new screen and samples below the rotating drum being manned in Figure 2.

uniform conditions were maintained. These tests were run in *lime, dolomite, sand, shale, and quartzitic sandstone. In all cases the results were the same.* In many instances the penetration rate doubled as the air passed through the rock bit.

EFFECTS ON GEOLOGICAL EVALUATION

Drill pipe buoyancy. Since the hole blows down considerably in aerated water drilling, the driller may have to pick up the drill pipe occasionally to observe the weight indicator reading. It is often found that with 10,000 feet of 4½-inch drill pipe in the hole, the buoyancy effect on the pipe may decrease until the weight indicator records 10,000 pounds of extra weight. This must be taken into consideration if the geologist wishes to compare conventional fluid drilling versus aerated water drilling. The geologist needs to understand this effect to prevent erroneous conclusions as to changes in drilling rate. The *effective* bit weight must be observed.

Lost circulation. Possibly the greatest field for aerated water drilling is in lost circulation areas. In drilling such an area, about one standard cubic foot of air added to one gallon of drilling fluid is generally sufficient to maintain circulation. Air volumes in excess of one cubic foot of air to one gallon of drilling fluid may result in faster drilling rate and *less lag in getting samples to the surface.* Also, greater hole washing possibly will result; this is especially true in the upper section of the hole.

The size of the aerated fluid sample chip at the time it is cut by the rock bit is probably about the same as the conventional mud drilled chip. The sample lag at low air/water ratios in aerated water drilling is substantially the same as in mud drilling. If a circulation check is made using a marker such as carbide, paper towels, oats, wheat, or rice, it is found that the marker returns across the shale shaker in about the theoretical time required for the drilling fluid (without the air) to circulate. If the volume of air is increased considerably, then the drilling fluid flows at a higher rate near the surface and the result is a somewhat decreased circulating time.

In aerated fluid drilling the average fluid circulating velocity in the annulus is generally less than 100 feet per minute. The rate at the surface may be several hundred feet per minute. This high annular velocity would depend on the air/fluid ratio. The high rate results in the hole being partially unloaded. Air expands as it approaches the surface; the high velocity results in some washing effect on the hole.

Therefore, the geologist may find cuttings from about any section of the hole that will erode in the samples. *These erosion samples are easily*

FIGURE 4—This photograph shows an estimated 15,000 barrels of salt water per hour escaping from a 10¾-inch flow line. Note the shale shaker screen below the pipe. A baffle plate in the line diverts part of the water returns and samples to the screen.

detected; they are generally rounded by their movement or from mechanical action of the drill pipe.

Cuttings. Most hard limestones, all dolomites, and harder formations are not affected abnormally by the presence of air in drilling fluid. That is, the sample will be substantially the same size and will retain its angular form in aerated fluid drilling about as well as in mud drilling. In deep holes where long strings of casing have been set or long sections of hard formation have been penetrated, the aerated water sample size may be somewhat smaller than the aerated mud or conventional mud sample. This is possibly due in part to the fact that there is very little if any wall cake on the formation in aerated water drilling.

The water returned in aerated water drilling is generally clear; the sample does not require washing. In the upper section of the hole the *color changes* in the formation can be seen very easily as the cuttings cross the shale shaker. As the depth increases the percentage of upper hole material also increases. Cuttings also have a tendency to slow down in cavities which are drilled at great depths. As a result, the samples recovered contain a smaller portion of the bit cuttings and a larger portion of sloughings.

Eventually, however, formation material from the washed out section in the upper portion of the hole gradually decreases and almost stops after the hole washes out enough to reduce the velocity of returns through that section. The net result is that a fairly constant volume of cuttings will be coming across the shale shaker and the drilling rate will slow down as the harder formations are drilled. Therefore, the proportion of sample actually being drilled continually decreases.

Hence, an error in the geologist's sample log may develop if he plots formation percentages without close observance of derrick floor drilling conditions. The geologist must watch very carefully for something new to appear in the sample. He may detect something new, then go back and find traces of the new material in the previous or earlier samples.

The finer material arrives at the surface first when drilling at great depths or if drilling in a cavernous area, such as is found in British Honduras and offshore from Key West, Fla. Some of this fine material will pass through a 20 by 30 mesh shale shaker screen; the coarser material generally follows in the next sample or so.

In exploratory drilling the geologist may wish to core occasionally for correlation at critical points, especially if he is using fossils for control. In shallow drilling—5,000 to 7,500 feet—cuttings are generally in good enough shape and size to be identified by a micropaleontologist. In deep drilling trouble may be experienced in following the fossil sequence.

It is not uncommon to have formation fragments from shallow depths, 2,500 feet or so, that may weigh 2 to 3 pounds. Some have been blown out which weigh as much as 6 pounds. These are believed to be ledges that have been broken off by drill pipe action and erosion. They are blown out as soon as they are broken loose, rather than being broken up by the drill pipe. These cuttings emerge in small fragments, as is the case in mud drilling.

Due to the fact that the annulus is filled with a combination of fluid and air, the well has a tendency to load up and flow off. In such cases samples do not come out continuously. In some instances in fast drilling a 30-foot single may be drilled down without returns reaching the surface. Then the well may flow off while the connection is being made or later. The drilling engineer can generally change the air/fluid ratio or other operating characteristics to improve this condition.

Occasionally a very prolific water-bearing formation is penetrated. The water flow in such cases may be considerable. In British Honduras one well produced fresh water in excess of 3,000 barrels per hour; of course, the shale shaker could not handle so large a volume of water.

Figures 2 and 3 show photographs of the system set up to catch the sample. Some experimentation is generally required to adapt each sample catcher to the conditions encountered. For instance, offshore in Key West the samples were caught successfully while drilling with returns in excess of 15,000 barrels of salt water per hour. Figure 4 is a photograph of the 10¾ inch flow line and water system. A baffle plate in the 10¾-inch flow line deflected a small amount of water on a shaker screen and a large quantity of formation samples was caught.

Hard limestone, dolomite, consolidated sandstone, some shale and most hard formations can usually be aerated water drilled without difficulty with samples. The *softer* limestones such as chalk sometimes wash considerably and some of the cuttings emerge almost powder fine. Many

shales are not water sensitive; they generally do not give any trouble with geological identification. In case the sand is not cemented, or the shale is water sensitive, the nature of the material in place cannot be easily determined. This type of material does not lend itself to aerated water drilling because of sloughing, caving, or hole fill-up. Aerated mud must then be used.

Care must be exercised so that the hole is not allowed to blow down and permit formation water to enter the hole due to reduced hydrostatic pressure. Such sections are hard to handle mechanically and are cased off if economics permit.

Water sensitive shales generally will disintegrate when contacted by fresh water. Cuttings from these shales are extremely fine—almost powder fine—when circulated to the surface. An example of this type of shale is found in Springer beds in southern Oklahoma.

Moderately swelling clays generally do not give much trouble in aerated water drilling, especially if the circulated fluid is salt water. Swelling clays are extremely difficult for the geologist to identify The driller can generally determine the location of a possible swelling clay by a repetition of tight hole in one depth on successive trips soon after the section is penetrated. The hole generally can not close in while the well is being circulated.

Formation and drilling waters. If a wet formation produces salt water, the damage done to the rest of the hole is negligible. If fresh water is produced, then some trouble may develop from the action of fresh water on shale. There probably is no difference in the case of fresh or salt water on limestone or dolomite. No difference was noted in the one test in which the water produced was fresh. The well that produced salt water eroded about the same as the one that produced fresh water. Caliper surveys were very similar. As of January, 1960, no effort had been made to drill with aerated water through a salt section using fresh water. No trouble had been experienced when circulating aerated salt water to drill a salt section.

Oil or gas shows can be detected in almost exactly the same manner as in mud drilling. About the same instruments and equipment are used and the same techniques are employed. Since in aerated water drilling the produced well fluid may either be circulated back in the well or allowed to flow to the reserve pit, an auxiliary connection is generally made to permit gas sampling on the blooey line as well as at the shale shaker.

It is generally found that circulated water does *not* wash an oil show from the formation drilled. Oil shows are detected in exactly the same manner as in mud drilling. Also, the geologist has an added tool in aerated water drilling—the aerated water column probably results in a decreased hydrostatic head on the oil-bearing formation. The oil-bearing formation is allowed to produce into the aerated fluid stream. If there is only a small amount of oil, a rainbow show will immediately appear on the water pit. There is *less* possibility of passing up a small oil show in aerated water drilling than in mud drilling. Of course, a good oil show would be expected to produce.

The hydrocarbon odor is easy to detect in aerated water. This check is generally more useful to the geologist here than in mud drilling because the chemicals in the mud sometimes mask hydrocarbon odors.

The geologist is sometimes inclined to be somewhat optimistic about the shows encountered because they are generally much more positive in aerated water than in mud drilling.

Continuous gas analyzers or gas indicators are advantageous on aerated water drilled wells to determine the exact point of gas entry. In the reduced hydrostatic head drilling, gas will continue to be produced after the show has been passed through; therefore, the spot check method of gas detection is not recommended. After gas or oil has been found in a well the geologist may want to drill stem test to determine the exact quantity.

Sidewall cores can be taken in aerated fluid drilling as well as in conventional mud drilling. The same is true of conventional coring.

Electric logging can be done at any time in aerated water drilling. The resistivity of the fluid in the hole should be taken into consideration in analyzing the electric logs. The other logs can be analyzed in almost exactly the same manner as in mud drilled holes.

In aerated water drilling, as well as in conventional mud drilling, the more time the geologist can spend on the rig floor and the more he observes in respect to the mechanics of aerated water drilling, the better his sample log may be. Most geologists who have had much experience with this type drilling think their sample logs are as good, if not better, than their mud drilled well logs.

Since the fluid in the annulus is compressible, and the rapidity with which drilling conditions and other well characteristics change, it is very helpful if the drilling engineer can work in conjunction with the geologist.

ACKNOWLEDGMENT

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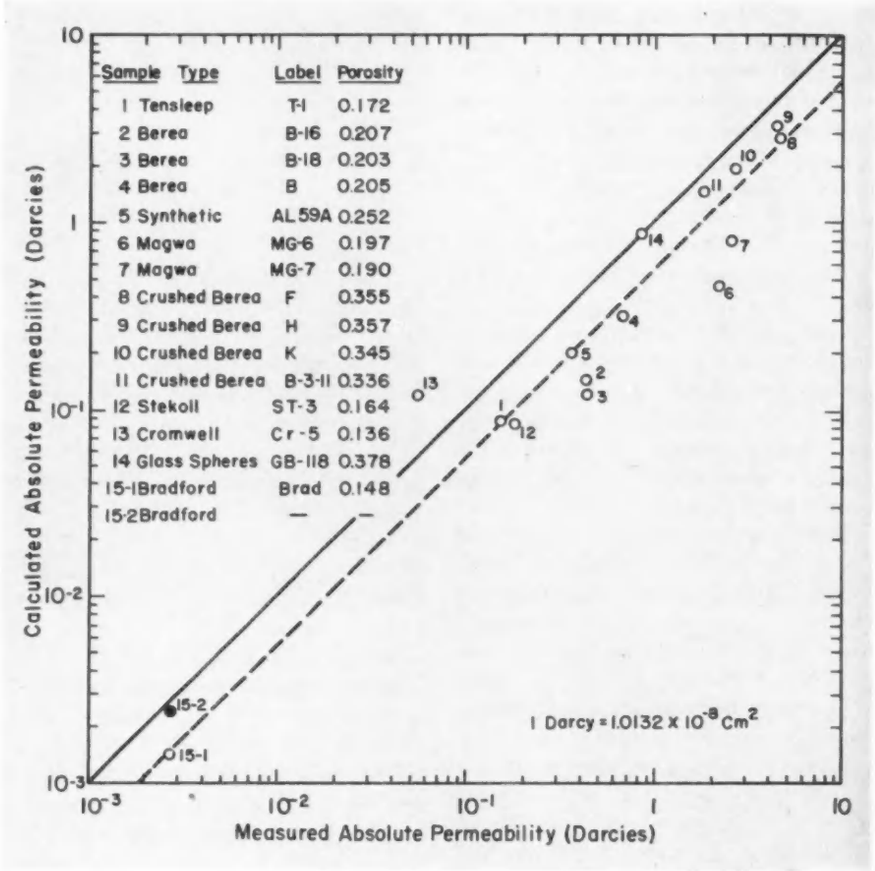

FIGURE 1—Here is a comparison of measured permeability with permeability calculated from Marshall's formula. Natural consolidated reservoir rock, synthetic consolidated material and unconsolidated aggregates are represented in this set of results. Permeabilities were calculated in all cases by replacing the integral in Equation (1) by the sum of 100 terms with equal saturation steps. Capillary pressure curves were measured with air displacing a C_{10}-C_{12} aliphatic hydrocarbon mixture, close cut. The wetting angle was assumed zero and the interfacial tension measured at 23.0 dynes per centimeter. Calculated values are consistently lower than measured values. If these low values are multiplied by a factor of about 1.8, agreement is obtained for the Tensleep sandstone, synthetic material (A1-59A) and crushed Berea-F which appears to be the most homogeneous and isotropic. This is indicated by the broken line. Stratification could account to some extent for scatter about this line. It is not purely coincidental that Burdine's formula for absolute permeability also predicts values which are low by a factor of 1.7. This has been discussed previously but the significance of the similarity is not apparent.[3]

Evaluating Marshall's formula for

Increased accuracy is feature of modified version. Calculated and experimentally measured results are compared

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THE RELATIONSHIP between capillary pressure and the permeability of porous media is a problem common to the petroleum engineer and the soil scientist. Their investigations, however, often proceed independently. Recent contributions to the problem from both fields of endeavor are compared and assessed in this article.

Recently, T. J. Marshall derived a formula for absolute and relative permeability,[1] which was based on a model for porous media described previously in the oil industry's literature.[2] Although derived from the same model, final formulas (in both cases) differed. To determine the significance of this difference, a series of measurements was made on various samples of porous media. Experimental results indicated a weakness in Marshall's formulas, calculated absolute permeabilities being too low by a constant factor and relative permeabilities too high. However, ideas used by Marshall were used to develop modified formulas which yield results that compare favorably with measured data.

Apart from its theoretical interest, a relation between permeability and capillary pressure data, if substantiated, would have useful applications. Permeability of small, broken or vugular reservoir samples usually can not be measured accurately. Capillary pressure curves, however, are obtained easily in these cases and rapidly if a mercury injection technique is used.

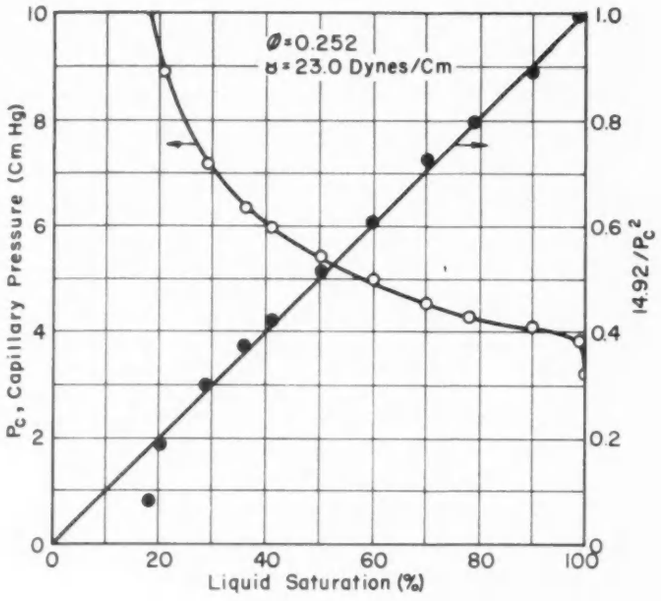

Figure 2

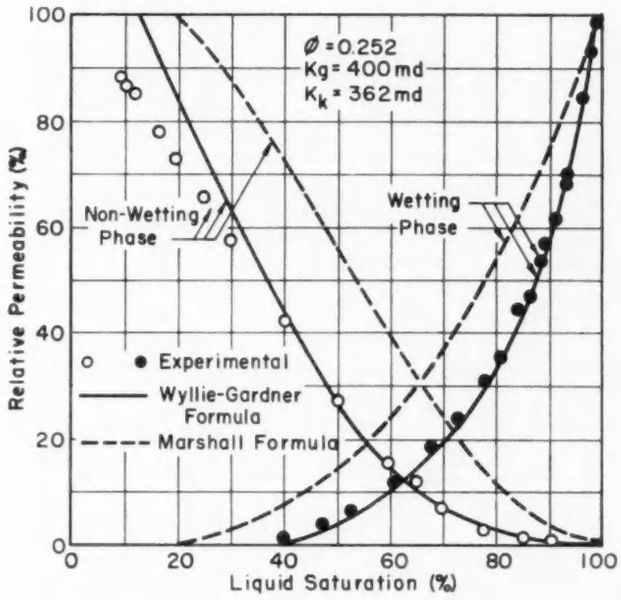

Figure 3

FIGURES 2 AND 3—A capillary pressure—saturation curve for a synthetic core (Al-59A) is shown in Figure 2 (left). Figure 3 (right) shows corresponding measured and calculated relative permeability curves. Typical of almost all samples, Figure 3 shows that Equations (2) and (3) grossly overestimate relative permeability. An exception was found with the MG-6 and MG-7 samples for which agreement is fair; however, absolute permeabilities (Figure 1) showed the poorest agreement in these cases. For comparison, the relative permeability calculated by another formula[2] also is shown. Using this formula, agreement with measured values for all the samples was good, except for the singular Magwa cores.

permeability

Absolute permeability. Marshall's formula for absolute permeability may be written in the form

$$K = \gamma^2\phi^2 \int_0^1 \frac{(1-S)\,dS}{P_c^2} \qquad (1)$$

where γ = interfacial tension, ϕ = porosity, P_c = equilibrium capillary pressure when the wetting phase saturation is S. The formula is remarkable in that it contains no empirical constants, as does the Kozeny-Carman equation. For any measured capillary pressure curve, the formula yields unequivocally a value for absolute permeability.

A comparison of measured and calculated absolute permeability (using Marshall's formula) for the samples examined is shown in Figure 1.

When calculating permeabilities by Equation (1), it is necessary to divide the range of integration into a large number of steps, especially when the irreducible saturation is high. For example, using about 15 subdivisions, Marshall calculates the permeability of a 2.7 md, Bradford sandstone with a 32 percent irreducible saturation as 2.4 md (Figure 1, 15-2). However, if the same calculation is performed using 100 subdivisions, predicted permeability is only 1.4 md. Strict application of the formula in this case again yields too small a value for absolute permeability. This low value, as shown in Figure 1, 15-1, lies close to the value predicted by the broken line.

Relative permeability. According to Marshall, relative permeabilities of the wetting phase and the nonwetting phase on the drainage cycle are given, respectively, by the formulas

$$k_{rw} = \int_0^{S_w} \frac{S_w - S}{P_c^2}\,dS \Big/ \int_0^1 \frac{1-S}{P_c^2}\,dS \qquad (2)$$

$$k_{rnw} = \int_{S_w}^1 \frac{1-S}{P_c^2}\,dS \Big/ \int_0^1 \frac{1-S}{P_c^2}\,dS \qquad (3)$$

where S_w denotes the wetting phase saturation. These formulas are not in close agreement with observation. Figure 2 shows the capillary pressure curve for a synthetic core (AL-59A) and Figure 3 the corresponding measured and calculated relative permeability curves.

In the past, formulas for relative permeability generally have been more successful than formulas for absolute permeability and it is somewhat disappointing to find a reversal of trend in this instance. An examination of

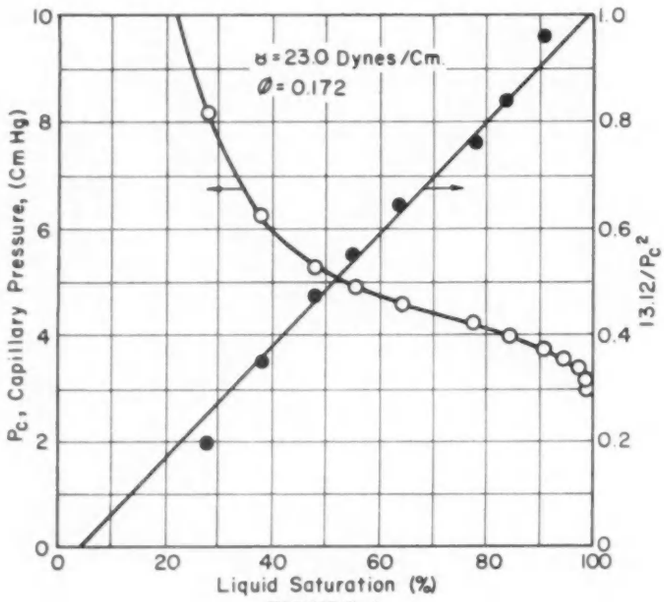

FIGURE 4

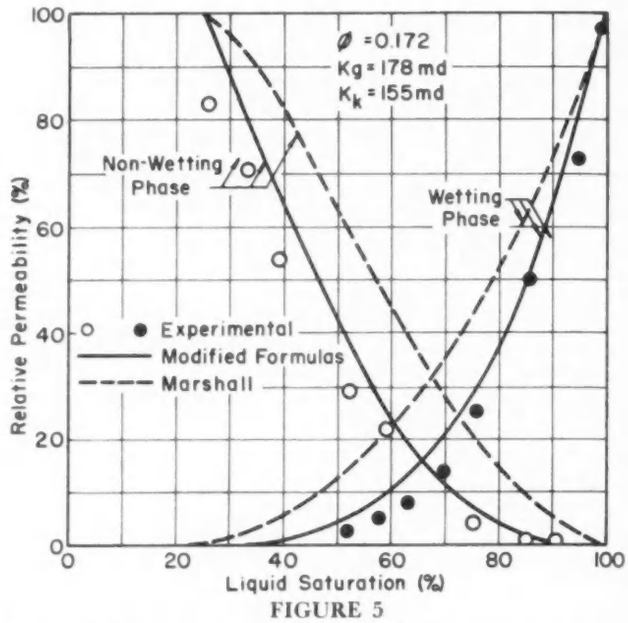

FIGURE 5

FIGURES 4 and 5—The measured capillary pressure curve for a Tensleep sandstone (T-1) is shown in Figure 4 (left). Figure 5 (right) shows the corresponding measured relative permeabilities, the curves calculated by Equations (2) and (3) and the curves calculated using the additional factors. Marshall's original formulas overestimate the relative permeabilities but the modified forms are more satisfactory. This behavior is typical of most samples examined.

Marshalls' derivation, however, suggests that this formula might be altered and thereby brought into closer accord with the model used. The final formulas differ from Equations (2) and (3) only in that the first is multiplied by a factor $(S_w - S_{wi})/(1 - S_{wi})$ and the second by $(1 - S_w)/(1 - S_{wi})$ where S_{wi} is the irreducible saturation.

It can be concluded from a study of the data presented in Figure 5 that the modified form of Marshall's formula predicts relative permeabilities with useful accuracy, at lease for reservoir rocks that are uniform. When stratification is pronounced, close agreement cannot be expected. Similarly, some modification of the formula for absolute permeability is required.

Derivation of the modified formula. The significant role of the irreducible wetting phase saturation S_{wi} should be recognized and considered. The simplest plan is to suppose that the irreducible liquid is immobile and may be treated as if it were part of the solid matrix. This implies that the permeability to gas is not altered by the presence or absence of the irreducible wetting phase. For some media this appears to be particularly true but a 10 percent increase in gas permeability below S_{wi} is not uncommon. Nevertheless, the assumption appears to give useful results. The permeability of the actual medium is calculated by consideration of the model with porosity ϕ^* and wetting saturation S_w^*, where $\phi^* = \phi(1 - S_{wi})$ and $S_w^* = (S_w - S_{wi})/(1 - S_{wi})$.

Two characteristic features of a porous body are carried over to the model. These are the concepts of pores and necks. For example, in a close packing of equal spherical particles, four adjacent spheres forming a tetrahedral structure surround a cavity or pore. Also, three adjacent spheres form a triangular configuration with a neck passing between them. Each such pore has four necks connecting it with other pores. Packings of a more irregular nature may have many particles forming the pores and more than three particles forming the necks.

When the non-wetting phase enters the medium and displaces part of the wetting phase, it may be visualized as forcing its way from pore to pore through the largest necks. At any given difference in pressure between the two phases, no neck smaller than a certain size determined by the interfacial tension can be penetrated by the non-wetting fluid. Thus, each pore is invaded according to the size of the largest neck leading to it. The irreducible wetting phase clings around the contacts between grains and tends to make circular the interface with the non-wetting fluid within a neck. For this reason, the interconnecting necks in the model may be treated as circular capillary tubes. The medium then is characterized by a distribution of pore sizes and a distribution of neck sizes.

A different sequence of events occurs on the imbibition cycle. When the wetting phase invades and displaces the non-wetting phase, it tends to accumulate in the necks which are the narrowest openings. If the wetting phase is allowed to imbibe freely, *any* neck is likely to become blocked because the wetting phase is not held back from any size of neck by the interfacial tension. It is plausible to assume that necks are blocked at *random*. When half the total number of necks are blocked it becomes impossible to find a path for the non-wetting phase through the medium which has not become blocked. Hence the permeability of the non-wetting phase becomes zero at the saturation corresponding to half the necks being filled. It seems not unreasonable to expect this saturation to occur near $S^* = 0.5$, and this is in agreement with observation.[3]

Explicit formulas for the drainage cycle only are considered here, for which many experimental results are available for comparison.

A typical cross section of a porous medium is imagined (in the model) to contain a characteristic distribution of circular pores. It is convenient to replace this general distribution by a step distribution in which each size of pore occupies the same fraction of the total area. This may be done without loss of generality and with any desired degree of accuracy by including enough steps.

When a pore of area A_1 is connected to a pore of area A_2, and A_1 is greater than A_2, it is assumed that the area of the connecting neck is fA_2, where f is a constant fraction characteristic of the structure. This is the fundamental idea introduced by Marshall and provides the link between the pore size distribution and the neck size distribution. It also would be assumed that f is equal to ϕ^*.

Flow through the connecting necks is calculated by use of Poiseuille's law, assuming that each neck is circular and has the same pressure drop. For a single capillary of area A, the flow per unit area is equal to $PA/8\pi\mu$, where P is the pressure gradient and μ the viscosity. For many capillaries of different sizes, but with each size having the *same total area,* the flow per unit area is equal to $P\overline{A}/8\pi\mu$, where $\overline{A}$ is the arithmetic mean of the different sizes. Thus, to calculate the total flow through the necks, and hence the permeability, it is sufficient to estimate the average neck area and the total neck area.

At a capillary prssure P_i only necks with radii greater than or equal to r_i are assumed to be penetrated where $P_i = 2\gamma/r_i$. This means that no pore smaller than A_i can be filled, where $\pi r_i^2 = fA_i$. A pore equal in area to A_i may not be invaded if it happens that *all* the pores to which it is connected are smaller than A_i. This is unlikely, except at low gas saturations, and therefore it is assumed that all pores greater than or equal to A_i are occupied by the non-wetting phase. Not all this fluid contributes to flow however, because there must be two necks greater than fA_i if fluid flows in and out of a pore.

Suppose there are N sizes of pores and that the first i have been invaded. Hence the saturation is given by $S_{nw}^* = i/N$ and the capillary pressure by $P_i = 2\gamma/r_i$. Assuming random interconnection, pores of any one size may be supposed divided into N groups each of which is connected to an equal number of pores of the N possible sizes. Thus the i invaded pore sizes give rise to i^2 sizes of invaded necks and the average radius $\bar{r}$ is given by

$$\bar{r}^2 = [r_1^2 + 3r_2^2 + \ldots + (2i-1)\, r_i^2]/i^2$$

When the bulk cross sectional area is A, assume that the total area occupied by pores in a typical cross section to flow is gA. It often is assumed that g is equal to the porosity although it is actually the void area/total area which numerically equals porosity. It would be more reasonable to suppose that the void area comprises the average of the pore and neck areas so that g would be greater than the porosity. The total area of the necks containing gas when the first i of the N pore sizes have been invaded is gAi^2/N^2. Not all these areas contribute to flow because a typical pore must have both an entrance and an exit before it can be considered permeable. The actual area available for flow is assumed to be $fgAi^3/N^3$, because the probability that a pore has a second neck large enough to admit flow is i/N.

Using Poiseuille's law and Darcy's law, permeability may be written

$$Kk_{rnw} = \frac{\gamma^2}{2} \cdot fg \frac{i}{N^3} [P_1^2 + 3P_2^2 + \ldots (2i-1)\, P_i^2] \quad (4)$$

In particular, when i = N, the formula gives the absolute permeability.

$$K = \frac{1}{2}\gamma^2 fg\, [P_1^2 + \ldots + (2N-1)\, P_n^2]/N^2$$

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Dr. G. H. F. Gardner graduated from Trinity College, Dublin, with a degree in mathematics and theoretical physics. He received his M.S. from Carnegie Institute of Technology and his Ph.D. from Princeton University in mathematics. Before joining Gulf Research and Development Co. in 1956 he taught mathematics in both Ireland and the United States.

Joseph H. Messmer graduated from Duquesne University in 1943 with a B.Ed. degree. He obtained the B.S. and M.S. degrees in chemical engineering from the University of Pittsburgh in 1949 and 1952, respectively. He has served as a research engineer in the petrophysics section of reservoir mechanics division of Gulf Research and Development Co. since 1957. Previously he was at Mellon Institute, Pittsburgh.

This coincides exactly with Marshall's formula if f and g are taken equal to ϕ^*. The experimental results indicate that f and g can be close to ϕ^* but usually are greater.

The permeability of the wetting phase may be written

$$Kk_{rw} = \frac{\gamma^2}{2} fg \frac{(N-i)}{N^3} [P_i^2 + 3P_{i+1}^2 + \ldots + (2N-2i-1)\, P_N^2] \quad (5)$$

Letting N tend to infinity and i/N tend to S_{nw}^*, Equations (4) and (5) may be rewritten in the form of definite integrals, which then coincide with the modified form of Equations (2) and (3). Equations (4) and (5) are suitable for numerical calculations as they stand.

Conclusions. For the majority of the experimental results studied, the formulas for relative permeability cited in reference 2 are in appreciably better agreement with measured values that even the modified form of Marshall's equations and the formula for absolute permeability given in reference 2 is equally as useful as Marshall's in as much as both require an empirical factor of about 1.8.

Several other general conclusions may be drawn:

(1) It is necessary in any theory to recognize the existence of the irreducible wetting phase saturation.

(2) The tortuosity factor of former theories can be replaced by the probability that an invaded pore has both an entrance neck and an exit neck large enough to admit flow.

(3) Some parameter in addition to the porosity may be required to characterize the structure of typical rocks.

(4) Relative permeability curves provide a good check on the accuracy of any proposed theory.

(5) Stratification can introduce profound effects on permeability measurements which are not reflected in the capillary pressure curves.

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How to stabilize long exposed shale sections

Deeper drilling depths and longer uncased intervals are imposing severe loads on the drilling fluids

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As well depths continue to increase the stabilization of the longer sections of exposed formation impose a severe load on the drilling fluid. The main problems of well bore instability are associated with shale bodies which undergo spontaneous self-dispersion upon contact with water or conventional drilling fluids. Filtrates from conventional muds suppress self-dispersion if the electrolyte concentration is 2-4 pounds per API barrel, but self-dispersion shales in contact with these solutions imbibe liquid and become soft and sensitive to mechanical disintegration.

Studies of the surface chemistry of clays led to a shale control mud system which couples a high filtrate calcium level with a controlled alkalinity environment. Samples of dispersing shale in contact with this filtrate undergo a progressive solidification so that, within reasonable time, they become hard and insensitive to even fresh water.

As the formation stabilization is attained by chemical means, the preparation and maintenance of shale control muds must be passed primarily upon chemical criteria. The proper alkalinity-calcium relationship for effective shale control results in a flocculated mud system. This flocculated system is stabilized and controlled by a floc-controlling or dispersing agent so that the mud has stable physical properties which are relatively insensitive to contaminants. The maintenance of the properly balanced relationships for shale control and stable mud properties is simplified by the use of a prepared shale control reagent.

The state of controlled flocculation is discused and the effect of dispersing and flocculating environments on mud properties and "mud-making" is illustrated. Mud systems which have been or are in common usage are compared.

In recent years the depth requirement of exploratory and development wells in the major sedimentary basins has increased rapidly. The 8,000-foot "deep test" of a few years ago is "top-hole" drilling today. With this increasing depth requirement, oil operators have been faced with the alternative of starting with larger and more costly well bores and cementing more and larger strings of casing in each well, or taking the calculated risks of drilling more footage of the smaller diameter hole between setting successive strings of protecting casing.

The stabilization of these longer sections of exposed open formations has imposed a severe load on the drilling fluids used, and in some areas the economic limit of drilling has been reached using the accepted standard drilling fluids of a few years ago. In many other areas deep drilling requires strict adherence to carefully prescribed mud properties. In these cases "mud economy" assumes a secondary role and philosophy of "anything reasonable for success" is required.

A critical review of the failures of the current muds to handle the problem of well bore stabilization successfully established three facts:

- The currently available muds have been so perfected as to rheology and formation sealing characteristics that further improvement in viscosity and filtration controlling agents for these systems would yield only nominal benefits.
- Although temperature stabiliza-

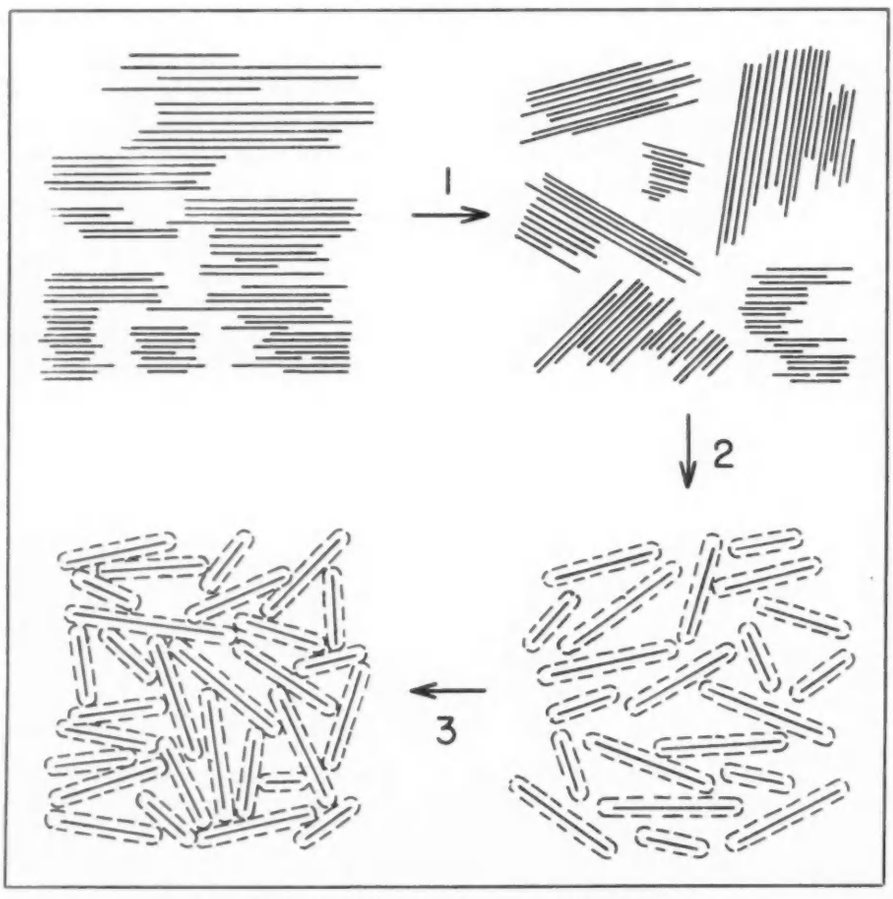


FIGURE 1—Life cycle of a mud-making shale.

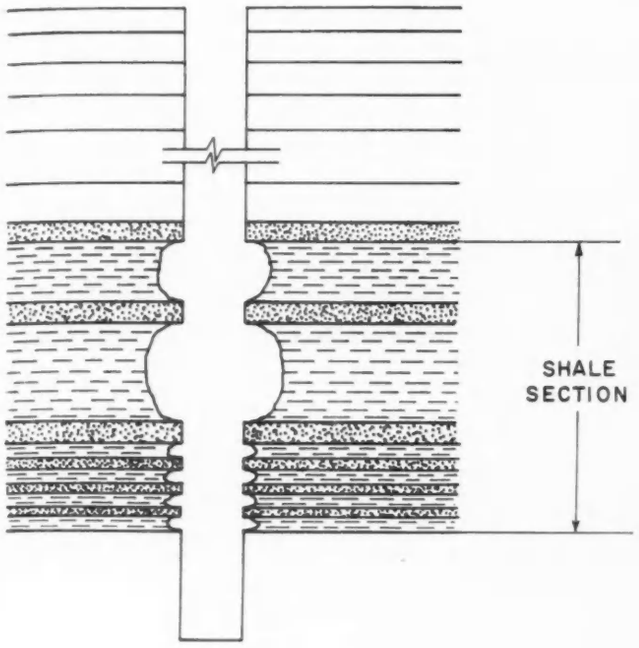
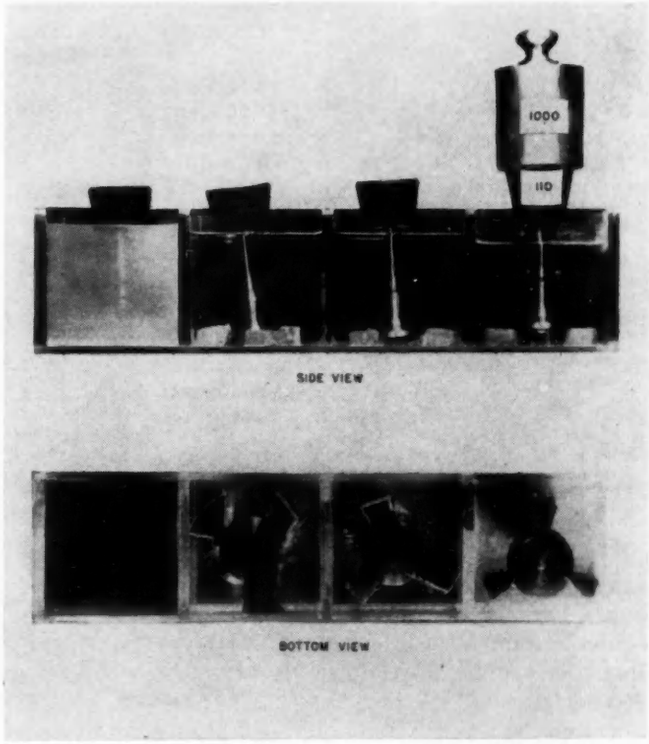


FIGURE 2—Deteriorating effect upon the well bore of self-dispersion of shale.



WATER	SATURATED GYPSUM Ca^{++} - 620 ppm	4 lbs / bbl CALCIUM CHLORIDE Ca^{++} - 4130 ppm	SHALE CONTROL FILTRATE Ca^{++} - 480 ppm

SOLUTION

FIGURE 3—Here is shown (right) the hardening action of the shale control filtrate in comparison to that obtained in simple electrolyte solutions.

tion may become an important factor in the future, most of the wells studied had come to an unsatisfactory termination due to well bore instability at temperatures well within the accepted temperature ranges of existing muds.

• The need for increased well bore stability required approaching the mud problem using a new parameter, i.e., the interaction betwen the mud, mud filtrate and the formation solids.

Shale well bore stability. In Figure 1, a representation of the life cycle of a mud-making shale is shown. Upon drilling, the grinding action first breaks the compacted material shown in the upper left hand corner into large chips or cuttings. As water attacks these cuttings, certain types swell and/or disperse into millions of microscopically fine fundamental clay particles which are intimately incorporated into the mud so as to increase viscosity severely. These particles may further regroup themselves as shown in the lower left so as to gel the mud to such an extent that it can no longer be used as a drilling fluid without major correction.

In the drilling of normal, well compacted, hard, black marine shales, the percentage of cuttings which disperse to fine clay particles, in the relatively short period of time betwen cuttings and arrival at surface screening devices, is small. Since additional mud volume is required as the well deepens, this limited shale dispersion causes little mud difficulty. Also, if the clays are well compacted, there is no abnormal well bore difficulty unless sections of this type of shale are encountered which are highly fractured by formation movement or are under abnormal stress conditions.

The main problems of well bore stability are associated with shale bodies which undergo spontaneous self-dispersion upon contact with

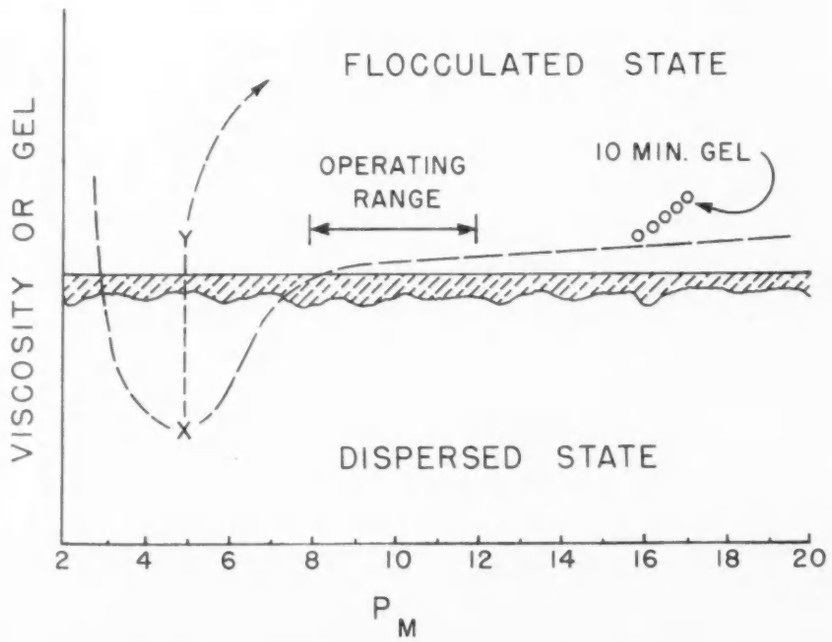


FIGURE 4—Effect of mud alkalinity on gel or viscosity.

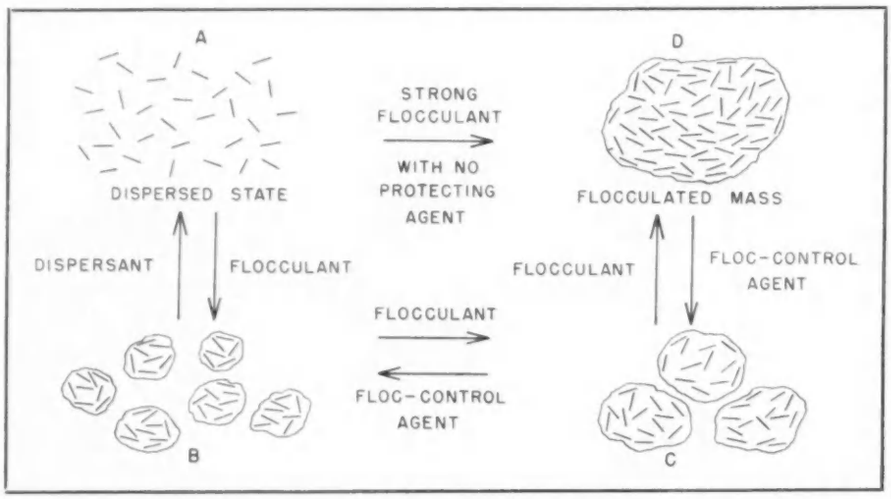


FIGURE 5—States of dispersion, flocculation, and controlled flocculation.

water or the conventional drilling muds. These shales often escape detection during the drilling program since they cannot be identified on the electric logs and, in severe cases, no representative intact cuttings reach the surface of a sufficient size to be separated and observed on the shale shaker screens. If a close geological or engineering check is being maintained on the mud system, these shales can be suspected when either the amount of cuttings recovered seems smaller for the amount of hole being drilled or the volume of new mud being formed is abnormally high per foot of hole drilled as reflected by the increased use of water, chemicals and weighting materials.

Figure 2 shows the deteriorating effect upon the well bore of this self-dispersion of shale. When undermining has reached a critical extent, the unsupported brittle shales and sands will collapse. This accounts for the widespread field observation that "heaving shales" are hard, brittle shales. From Figure 2, it is apparent that the "heave" is a result and not a cause, and that the heaved material, although responsible for sticking the drilling tools, is not the primary problem.

It is obvious that "heaving" is also a structural problem for, in highly dipping formations, the allowable extent of undermining is severely reduced. It is impossible at this time to identify this type of shale by any of the current logging techniques, but its fundamental difference is readily apparent in a simple experiment wherein undried fragments of the two types of shale are dropped into ordinary tap water. The normal shale will be unaffected, while a critical shale will be dispersed into mud even without agitation.

Any successful attack on the problems of well bore stability must deal primarily with preventing self-dispersion of the shales exposed in the well bore. In order to ascertain the primary factors responsible for the abnormal reaction of these self-dispersing shales, a large number of clays and shales were analyzed.

These studies were conducted to relate the type of shale disintegration to well bore instability, and established two distinct mechanisms in shale disintegration, namely: a physical change in shape and volume arising from swelling due to the inhibition of water, and a spontaneous disintegration without an appreciable change in volume, which we have given the designation "self-dispersion."

In line with these developments, it was noted that:

- Most of the commercial drilling mud bentonites, although exhibiting a high degree of swelling, are not normally of the self-dispersing type and require supplementary mechanical agitation for dispersion.
- Samples of severe "heaving" shales cored in Gulf Coast wells underwent spontaneous self-dispersion without appreciable swelling.

Some of the earlier attempts to drill the difficult sections of "heaving shale" included high concentrations of electrolytes such as salt and high pH caustic muds. Others have sought to use strongly adsorbed ions, calcium and magnesium brines, to suppress swelling of the clays. The approach of the study reported here was that of developing an environment which would stabilize the troublesome shale and of then developing a mud which would incorporate this environment.

In evaluating the effect of various solutions upon shale dispersion, it was found that many electrolyte solutions such as caustic soda, salt, calcium chloride, saturated gypsum and high pH limed mud filtrates, suppress disintegration by self dispersion at about the same level of electrolyte content, i.e., 2-4 pounds per API barrel. However, the self-dispersing shales in contact with these solutions inbibe liquid and develop a degree of soft incompetence which makes them very sensitive to mechanical disintegration.

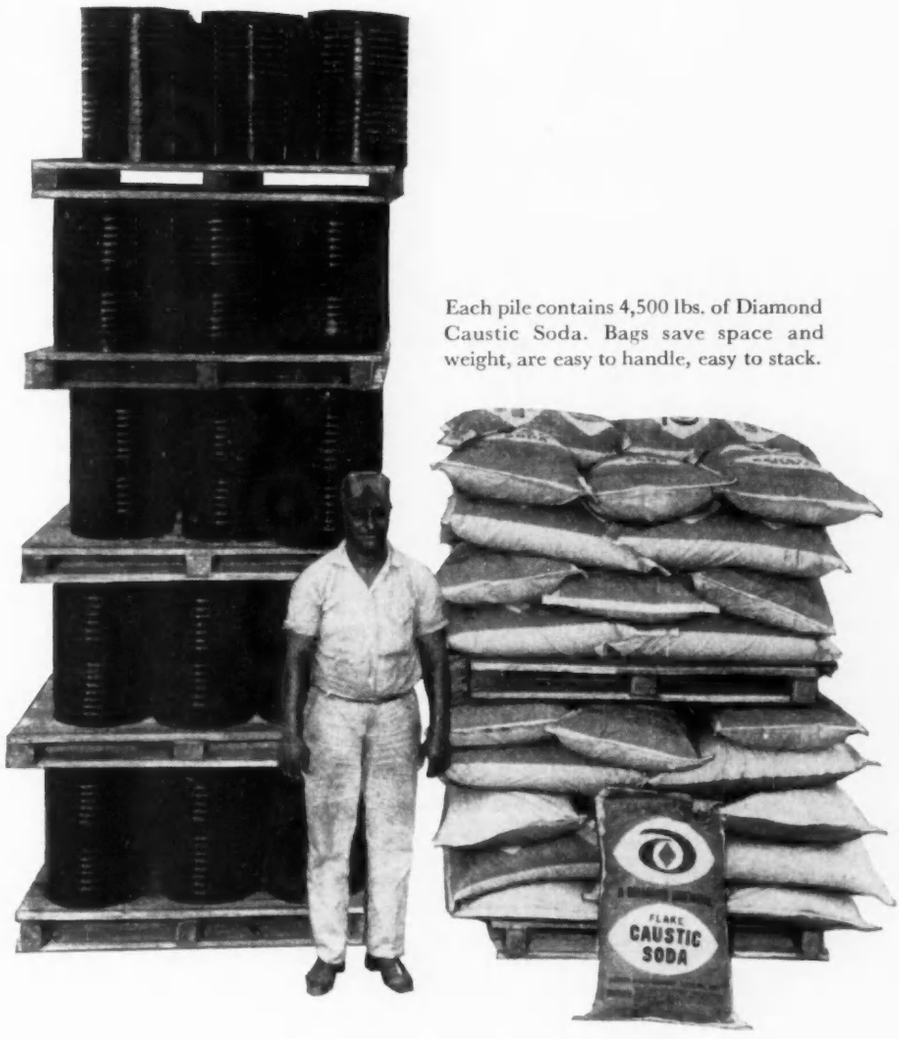
It is obvious that contact with any media which would result in the conversion of the sensitive shale to such an incompetent state would be entirely unsatisfactory, since the hydraulic turbulence of the circulating drilling fluid would be sufficient to cause severe well bore erosion and subsequent hole enlargement. This finding emphasized the danger of relying upon the simple visual observation of the dimensional stability of a shale fragment as a criterion of a successful shale controlling medium.

SHALE CONTROL BY VARIOUS MUD SYSTEMS

Simple muds. The clay-water muds, low pH caustic-quebracho muds, phosphate quebracho, and the high pH caustic-quebracho muds, with the possible exception of the latter, were designed to obtain maximum dispersion and mud yield from the formation cuttings. Therefore, they should not be expected to exhibit shale control in their generally used state. Studies on shale reaction demonstrated that the caustic-quebracho environment of the conventional high pH red mud also does not accomplish shale solidification.

Calcium base muds. From this study it was also apparent that muds composed of normal pH solutions of calcium salts, such as calcium chloride and calcium sulfate, will not increase shale stability.

Non-aqueous base muds. Oil base muds have been proposed for this application but, to the writer's knowledge, have not been used specifically for this purpose. The types of shale which present the major portion of the difficulty in "heaving shale" drilling are normally high water content massive shales with a putty-like con-



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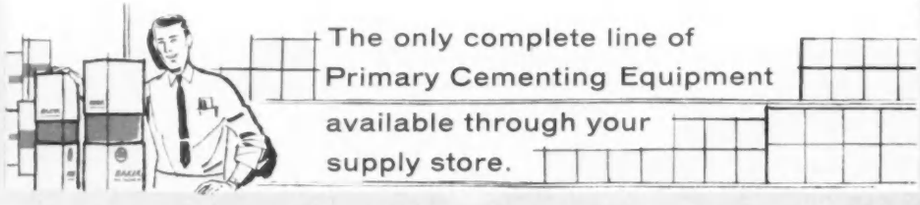

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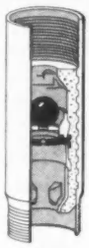
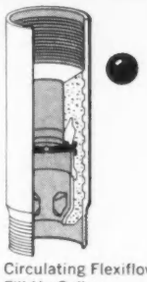
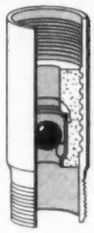


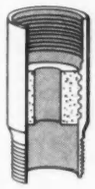
Flexiflow
Fill-Up Collar
Product No. 161 M&F



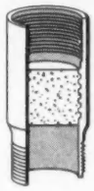
Circulating Flexiflow
Fill-Up Collar
Product No. 161-D M&F



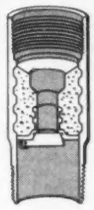
Cement Float Collar
Product No. 101 M&F



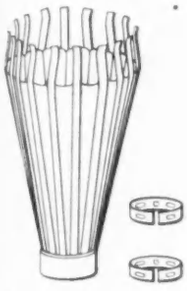
Cement Baffle Collar,
with Hole
Product No. 104 M&F



Cement Baffle Collar,
Solid
Product No. 105 M&F



Triplex
Flapper Valve
Float Collar,
Product No. 134 M&F



Metal Petal Basket,
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Product No. 343

Plain Hook-Up Nipple
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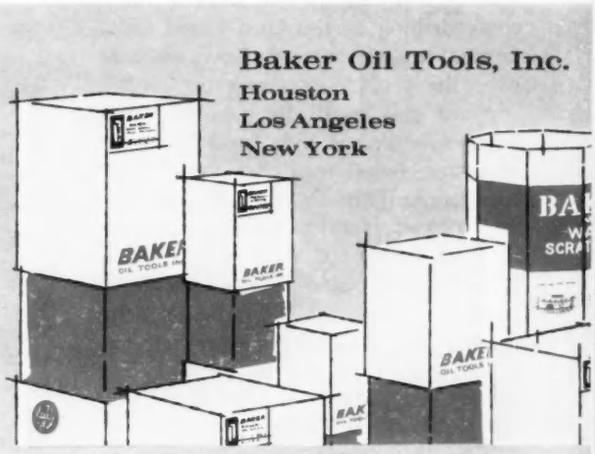
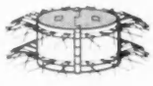
Product No. 330

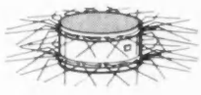
Avoid welding . . .
lock casing shoes
and collars with
BAKERLOK
Thread-Locking
Compound
Product 050



Hinge-Lok Wall
Scratcher, with
4½" long wires
Product No. 900-C



Hinge-Lok Wall
Scratcher, with
2½" long wires
Product No. 900-C



Solid-Ring Wall
Scratcher, with
4½" long wires
Product No. 901-C

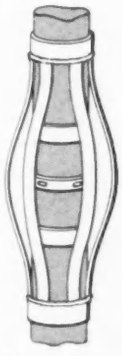
Solid-Ring Wall
Scratcher, with
2½" long wires
Product No. 901-C

Hammer-Lok
Stop Rings
Product Nos.
940-B (Solid)
and 945-B (Hinged)

Rotating
Wall Scratcher
Product No. 903

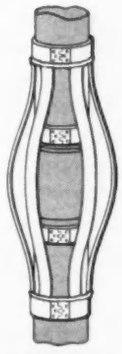
"G-12" Slim Hole
Casing Centralizer
Product No. 910-G

"HN-15" Solid-Ring
Casing Centralizer
Product No. 908-HN

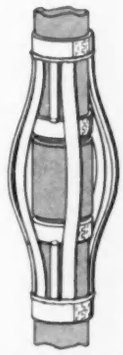


"HN-20" Solid-Ring
Casing Centralizer
Product No. 908-HN

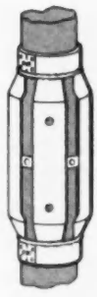
"H-15" Hinge-Lok
Casing Centralizer
Product No. 9115



"H-20" Hinge-Lok
Casing Centralizer
Product No. 9112

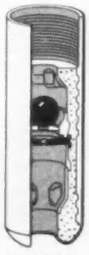


"H-25" Hinge-Lok
Casing Centralizer
Product No. 9113

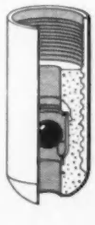


Hinge-Lok Rigid
Casing Centralizer
Product No. 9133

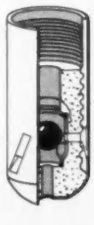
Differential
Fill-Up Shoe
Product No. 1081



Flexiflow
Fill-Up Shoe
Product No. 160

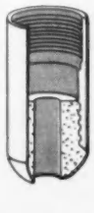


Cement
Float Shoe
Product No. 100



Cement Wash-Down
Whirler Float Shoe
Product No. 120

Cement
Bull Plug Shoe
Product No. 103



Cement Guide Shoe
Product No. 102

Triplex Cementing Shoe Product No. 1363

sistency which would tend to admix severely with an oil base mud. The degree of success in using such a fluid would be closely related to its ability to tolerate high water and solids contamination.

High pH red limed muds. In the past the high pH red lime mud has been the most highly developed and widely practiced procedure in use of shale drilling in the Gulf Coast area. Several misconceptions have evolved over the years concerning the chemistry of this mud. By far the most erroneous idea is that the clay solids in a red limed mud are "converted to a calcium base." Since the calcium ion content is suppressed severely by massive treatment with caustic soda while at the same time the sodium level is being raised radically, the theories of base exchange predict that there should be no appreciable increase in calcium saturation on the clay.

To substantiate this prediction in an active mud system, a study was made to determine what change in the exchangeable bases on the mud solids occur during conversion and maintenance of a high pH limed mud. Table 1 presents the results of that study. In eighteen days, approximately 8,700 pounds of caustic soda, 26,000 pounds of lime and 14,500 pounds of dispersant (10,500 pounds of quebracho plus 4,000 pounds of calcium lignosulfonate) were added to a mud system of approximately 1,200 pounds, yet they produced no significant change in the exchangeable bases on the clays present in the mud.

In line with theory, but contrary to common thinking, it can readily be seen that the high pH limed mud system produced little or no change in the relative Ca:Na saturations of the clays and shales despite the massive additions of chemicals. It was further found that self-dispersing shales will soften and lose physical strength in contact with filtrates from such muds.

TABLE 1—Surface Chemistry of Mud Solids in a Typical High pH Limed Mud

Approx. Depth (feet)	Sodium Saturation On Clay Solids (percent)	Time of Sampling
6875	72.6	2 PM—Day before "conversion" (native hole mud)
	71.6	4 PM
	70.1	10 PM—Immediately preceding "conversion"
	71.4 Average	
"Conversion" between 10AM—2 PM. Chemicals added: 5 lb/bbl lime, 2 lb/bbl NaOH, 3 lb/bbl Quebracho.		
6950	96.2	4 PM—Immediately following "conversion"
7500	73.7	4 days after "conversion"
7700	73.1	5 days after "conversion"
8000	65.9	8 days after "conversion"
8550	79.5	12 days after "conversion"
8820	68.9	15 days after "conversion"
9050	74.9	18 days after "conversion"
	72.7 Average	

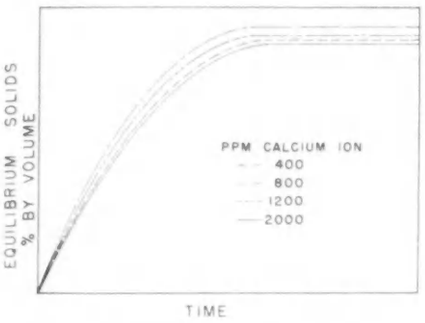


FIGURE 6—Effect of calcium concentration on equilibrium solids level.

Silicate muds. The only successful approach prior to this time in shale consolidation has been the silicate mud. Specimens of the soft incompetent self-dispersing shale in contact with the high electrolyte, controlled sodium silicate environment develop a "case hardening" which not only stabilizes the shale fragments but also imparts mechanical strength. This hardening appears to have a limiting depth of penetration, for specimens so treated if later broken and placed in fresh water disperse on the newly fractured surface and leave a shell of the hardened shale as a residue.

PRESENT SHALE CONTROL MUD SYSTEM

Shale control environment. Studies of the chemistry involved in reactions with clay containing materials led to the present shale control mud system which, by coupling a high filtrate calcium level with a controlled alkalinity environment develops shale stabilization by a process of progressive solidification, which is similar to that previously only partially obtainable by use of the silicate muds.

Samples of dispersing shale placed in contact with controlled alkalinite, high calcium mud filtrate undergo a progressive solidification which, within reasonable time, renders them as hard and rigid in character as chips of highly compacted normal shale. The solidification obtained by use of this system differs from that obtained in the controlled silicate environment in that the solution with time penetrates the dispersing shale specimens completely, and the solidification is such that they will remain stable upon later extended exposure to fresh water even when mechanically broken into numerous small fragments.

Figure 3 demonstrates the hardening action of the shale control filtrate in comparison to that obtained in simple electrolyte solutions which also possess equal or greater calcium contents, as previously discussed under "calcium base muds." The fresh water chamber shows how the shale fragments underwent self-dispersion. This dispersion occurred in 16 hours without any change in dimension of the fragments (swelling) and without supplementary mechanical agitation. Although retaining their original dimension, the specimens in the simple solutions developed no mechanical strength, whereas those in contact with the shale control filtrate underwent progressive solidification to a point where the mere tops of the specimens would support a load of over 1,100 grams with no indication of weakness.

Shale control mud. Having established the shale control enviroment, the problem was to incorporate this high calcium, controlled alkalinity environment into a fluid which would possess satisfactory physical properties for use as a drilling mud, and which could be successfull maintained over long periods of time while drilling under a wide variety of conditions.

This can best be obtained by use of a fundamentally all calcium salt system which is flocculated and restabilized or dispersed to yield a high degree of stability with simplified maintenance.

To assist in the formulation and maintenance of properly balanced shale control chemistry with good physical mud properties, "shale control reagents" are available from various mud additive manufacturers.

Shale control mud characteristics. Because shale control muds are used

a Baroid Mud Program

MUD PROBLEM

...and its solution

This case history shows again how a complete Baroid mud program helps accomplish your drilling objective. A costly fishing operation was prevented by the use of the specific product TRIMULSO.

Baroid's previous experience enabled the diagnosis of the potentially costly fishing job that would result from differential sticking. Previous experience also resulted in prevention of the trouble by the engineered use of TRIMULSO.

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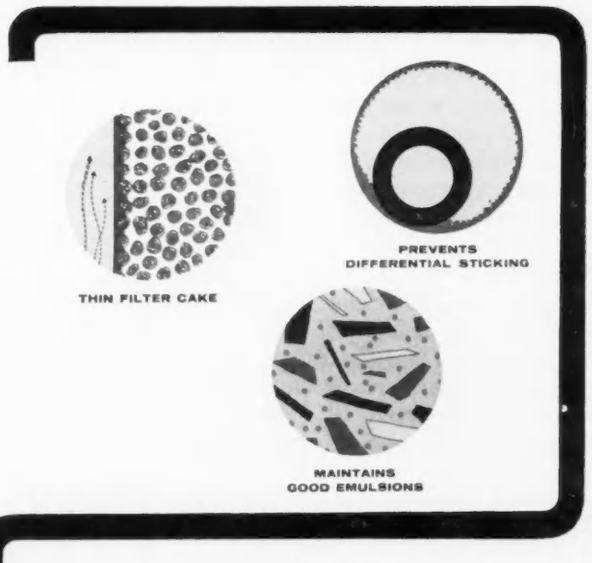

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for formation stabilization they must be controlled primarily by chemical analysis of the mud and filtrate to make certain that the proper chemical relations are being maintained to insure the desired shale reactions. The physical properties are then adjusted, but only in a manner which will not be detrimental to shale stability. It is important to emphasize the necessity for chemical control of this mud, as it is possible for inexperienced personnel to fail to obtain the full advantages of the system of the maintenance program is based on physical properties alone.

Alkalinity-calcium relations. When a properly balanced shale control reagent is used, the calcium alkalinity relationships are established and the mud can be field controlled by maintenance of the mud alkalinity, P_m, with a nominal amount of engineering supervision.

Control of the shale and of the state of flocculation or dispersion of mud is related to the alkalinity control of the whole mud, and it is important that the controlled flocculation state be maintained to insure stable physical properties in the system.

Figure 4 is an idealized representation of the complex relationships between viscosity or gel, and mud alkalinite, P_m, in the controlled flocculated and dispersed states. When a mud has been properly converted with shale control reagent to a P_m of 8 cubic centimeters or above and a filtrate calcium level of at least 400 ppm, the mud is in a satisfactorily controlled flocculated state and, as long as it is maintained in an operating range of 8-12 cubic centimeters P_m with a calcium ion level of 400-1000 ppm, the addition of shale control reagent for maintenance proceeds with no abnormal reaction in regard to viscosities or gels.

However, if the chemical levels are allowed to drop, the mud moves towards a dispersed state. As the mud begins to disperse the gels drop toward the 0-0 values associated with dispersed muds, the viscosity drops, and the physical appearance of the mud seems to improve. It is here that the value of "control by chemistry" can be appreciated. This apparent improvement could continue until the point is reached where the floc-controlling agent or dispersant becomes too low in concentration or moves out of its range of effective operation. At this point the mud will flocculate rapidly and severely with damage to the whole system. Fortunately this condition is preceded by a much less severe effect. As the chemical balance drifts towards the dispersed state, cutting preservation efficiency weakens and viscosity build-up starts. This viscosity rise is shown in the diagram by the dotted line X-Y (Figure 4).

When the viscosity rises to a point requiring correction, Y, and correction is attempted by use of shale control reagent, the high content of partially dispersed solids will not return to the floc-controlled state without developing intolerable viscosity and gel. The only simple way to return successfully again to the desired flocculated state of the shale control mud at this time is to reduce solids rapidly and rebuild the chemical balance before additional cutting dispersion can again raise the viscosity level.

This condition may be considered to be due to personnel failure, as the system is simple to maintain within a wide operating range and there is no need for such a condition ever to arise unless it is flagrantly neglected.

It will be noted on the diagram that a rise in the 10 minute gel value is shown for abnormally high alkalinites. To the writers' knowledge this has only occurred once and at a time when it has been necessary to drill approximately 1,000 feet of flash-set cement from a string of 7-inch casing. The difficulty appears to arise from an inability of the floc controlling or dispersing agent to control the floc completely under such a severe condition. After the maintenance treatment was reduced, the P_m dropped in a short time, and the condition rapidly corrected itself.

In Figure 4 the shaded area indicates that there exists an area of demarcation and not a distinct boundary between the flocculated and dispersed states. In this area exist many degrees of flocculation and dispersion depending on numerous factors such as: (1) Concentration of and ratio of flocculating and dispersing agents, (2) nature and relative effectiveness of flocculating and dispersing agents, and (3) susceptibility of solids and system to flocculation. In the shale control system the point of entry into flocculated state appears to be more readily definable than a point of re-entry into the dispersed state. Moreover, in this study the flocculated state has been more thoroughly investigated, and the area of re-entry into the dispersed state has been of only academic interest since a shale control system should never be allowed to operate under this condition.

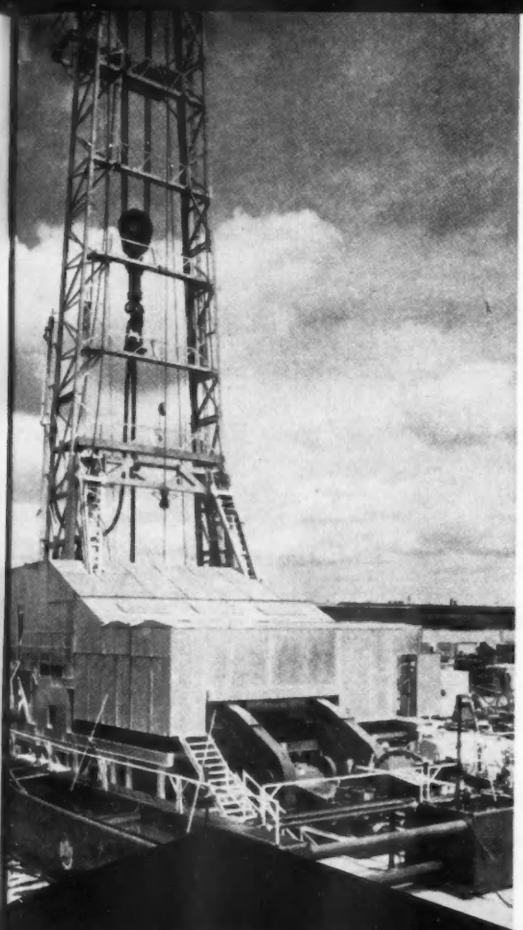
The controlled floc state. Figure 5 is a pictorial representation of inter-

TABLE 2—Effect of Controlled Flocculation On Mud Making Properties

Depth Interval (Feet)	Amount Drilled (Feet)	Mud Weights Over Interval (Lbs./Gal.)	WEIGHT MATERIAL CONSUMPTION	
			Theoretical (Cwt.)	Actual (Cwt.)
Normal Shale Control Mud Program				
9,316—10,141	825	13.1 to 15.7	2718	2908
10,141—10,262	121	15.7 to 16.0	320	425
0—10,262	...	9.8 to 16.0	6588	6647
Period of Abnormal Floc-Controlling Agent Usage				
10,262—11,164	900	16.0 to 15.8	147	1988
11,164—11,463	300	15.8 to 15.8	129	1035
Mud Balance Corrected to Normal "Controlled Floc" State				
11,463—11,831	368	15.8 to 16.0	403	430

TABLE 3—Surface Chemistry of Mud Solids in a Shale Control Mud

Sample	Depth (Feet)	Sodium Saturation on the Clay Solids (Percent)	Time of Sampling	Filtrate Calcium Ion (ppm)
A	5500	65.3	Before conversion	...
B	5600	23.7	After conversion	735
C	6500	29.1	4 days after conversion	400
D	7220	34.4	8 days after conversion	425
E	7500	28.1	10 days after conversion	390
F	7800	28.7	12 days after conversion	380



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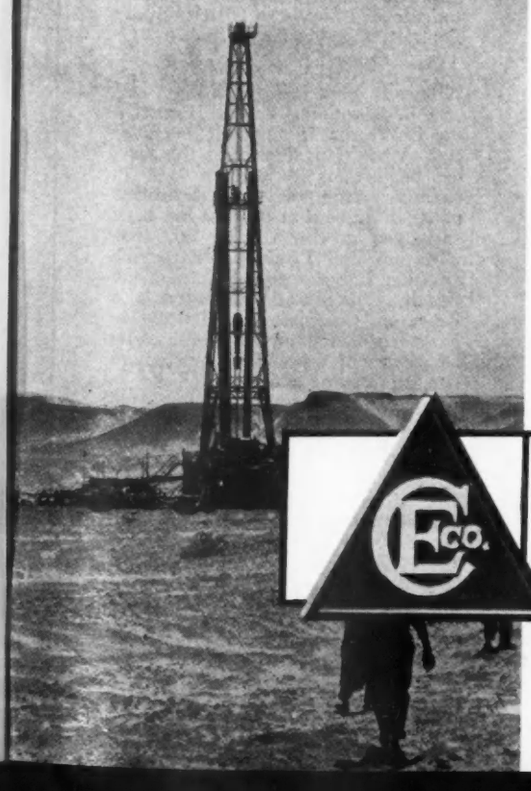

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TABLE 4—Comparison of Muds Used in Shale Drilling

Feature	Shale Control Mud	Silicate Mud	Simple Low pH Muds Caustic-Quebracho, Phosphate, Etc.	High pH Caustic Quebracho Muds
Type of System	Controlled floc	Flocculated	Dispersed	Dispersed
Shale Reaction	Solidifying	Solidifying	Dispersing	Softening
Well Bore Reaction	Stabilizing	Stabilizing	Sometimes deteriorating	Erosion sensitive
Mud Making Properties	Very low	Very low	High	High
Original Cost	Moderate	High	Low	Low-moderate
Maintenance Cost For High Weight Mud in Shale Drilling	Low	High	Very High	High
Conversion Mud Base	Hole	Compounded	Hole	Hole
Primary Treating Agents	Single powdered material	Mixture compounded at rig	Mixture compounded at rig	Mixture compounded at rig
Control Procedures	Simple	Involved	Simple	Simple
Filtration Control Mechanism	Organic agent	Uncontrolled	High dispersion-organic agent	High dispersion-organic agent
Filtration Value Maintained	Moderate	Uncontrolled	Moderate	Moderate-low
Emulsifying Power	Excellent	Not used with oil	Emulsifier required	Emulsifier often required
Temperature Resistance As Normally Used	Fair	Never fully evaluated—appears good	Good except phosphate mud	Fair
Contamination Resistance (Salt)	Excellent	Excellent	Poor	Fair
(Calcium)	Excellent	Undetermined	Poor	Fair
Logging Characteristic	Good with calcium correction	Complicated	Good	Good

Feature	CALCIUM MUDS* Low pH	CALCIUM MUDS* High pH	Saturated Salt Muds*	Synthetic Surfactant Muds
Type of System	Dispersed**	Dispersed	Flocculated	Controlled floc
Shale Reaction	Softening	Softening	Softening	Softening
Well Bore Reaction	Erosion sensitive	Erosion sensitive	Erosion sensitive	Erosion sensitive
Mud Making Properties	High**	Moderate	Low	Moderate
Original Cost	Moderate	Moderate	Moderate	High
Maintenance Cost For High Weight Mud in Shale Drilling	Moderate-high	Moderate-high	High	Moderate-high
Conversion Mud Base	Hole	Hole	Compounded	Compounded
Primary Treating Agents	Mixture compounded at rig	Mixture compounded at rig	Mixture compounded at rig	Mixture compounded at rig
Control Procedures	Simple	Simple-involved	Simple	Involved
Filtration Control Mechanism	High dispersion**—organic agent	High dispersion organic agent	Organic agent	Organic agent
Filtration Value Maintained	Moderate	Moderate-low	Moderate	Moderate-low
Emulsifying Power	Excellent	Emulsifier often required	Emulsifier required	Emulsifier required
Temperature Resistance As Normally Used	Fair	Fair	Not fully evaluated—appears good	Excellent
Contamination Resistance (Salt)	Excellent	Good	Excellent	Excellent
(Calcium)	Excellent	Good	Fair-poor	Excellent-poor
Logging Characteristic	Good with calcium correction	Good	Complicated	Calcium type needs calcium correction

* Exclusive of Synthetic Surfactant Muds.
** As Normally Practiced.

related states of dispersion, flocculation and controlled flocculation.

In the dispersed mud systems, heavy treatment with dispersants is employed in an effort to maintain as nearly as possible a completely dispersed state (A) between the clay particles. Opposing this dispersion is the influence of flocculants and flocculating influences such as salt gypsum, high solids state heat and even in some cases the chemicals originally added to aid the dispersion (over-treating effects), which tend to shift the system towards the partially occulated state (B).

The success of dispersion depends upon many factors such as the effectiveness and concentration of dispersant, the flocculation efficiency of the flocculants, and the nature of the system being subjected to flocculation. Calcium salts are normally considered to be severe flocculants but, in one presently used system, a system saturated with gypsum is effectively dispersed by massive treatments of dispersant.

The shale control mud system relies upon controlled flocculation, i.e., the calcium flocculants are capable of flocculating the originally dispersed clays to a mass flocculated state (D). Floc controlling or dispersing agents

About the Authors

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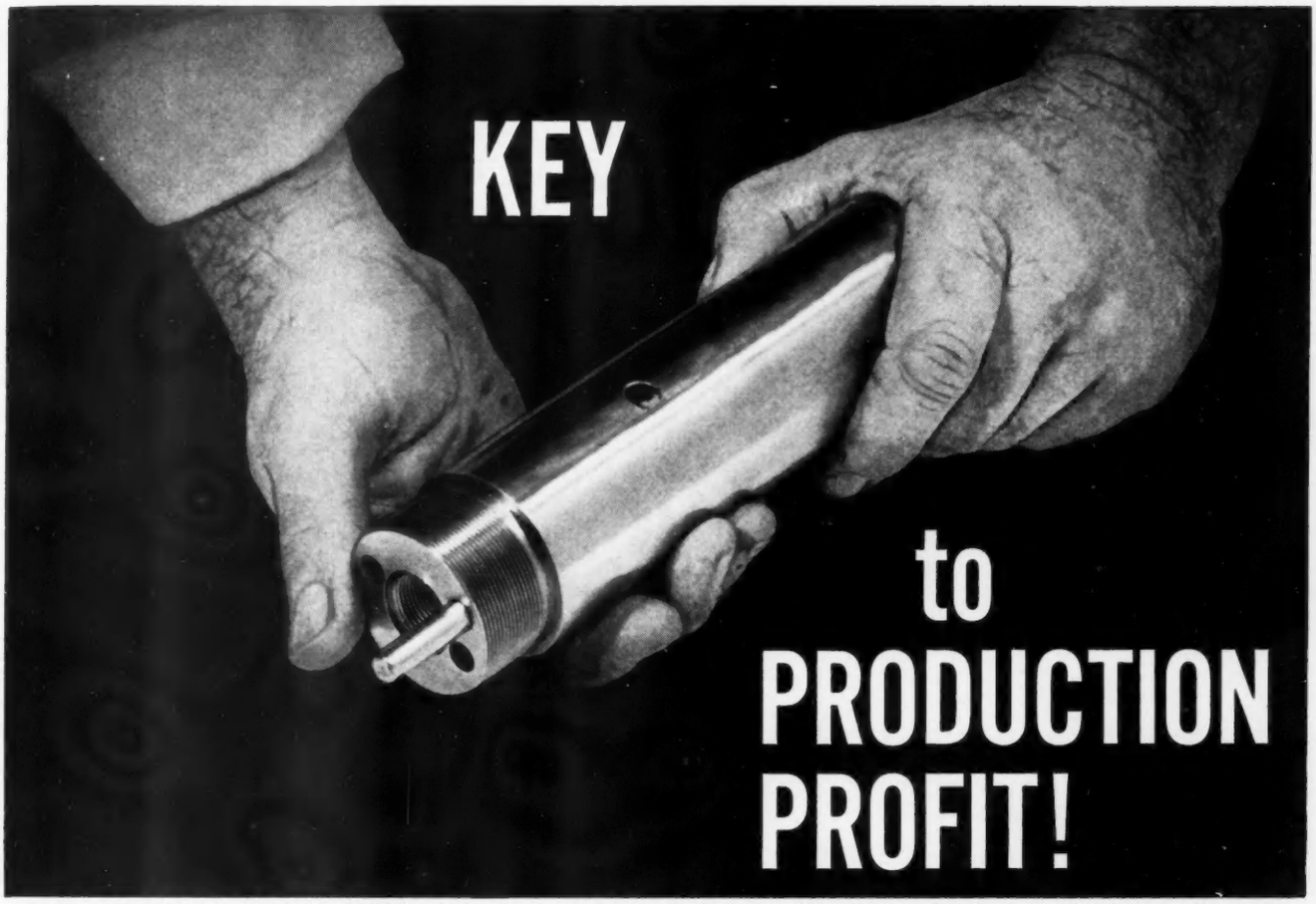
Walter J. Weiss is group leader in clay research with the Exploration and Production Division of the Research and Technical Department of Texaco Inc., at Bellaire, Texas. He was graduated from the University of California at Los Angeles in June 1935, and received his M.S. degree from the University of Southern California in 1936. In May 1937, he entered Texaco's Production and Natural Gasoline Laboratory at Signal Hill, Calif., engaging in drilling fluid research and field engineering. In 1952, while engaged in clay chemistry research, he was transferred to Bellaire and has continued studies in this field since that time. A registered engineer in California, he is a member of AIME and the API Southern District Study Committee on Drilling Fluids.

Wilbur L. Hall received his B.S. degree in mechanical engineering from the California Institute of Technology. After returning from the service he graduated with a B.S. in chemistry from the same institution in 1948. Since that time he has been employed in the Texaco Inc., Exploration and Production Research Division Laboratories, first in Long Beach, Calif., and currently is a Research Chemist at Bellaire. He has been associated with practically all phases of the control and chemistry of drilling fluids.

Richard H. Graves is a research chemist with the Exploration and Production Division of the Research and Technical Department of Texaco Inc., at Bellaire. He was graduated from the University of Kentucky in June 1954, with a Ph.D. degree in physical chemistry and has been with Texaco at Bellaire since that time.



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are then employed to reduce this massive floc system to one of controlled size as idealized by stages (C) and (B).

Being in this transitional state of controlled flocs, the shale control mud system possesses a great tolerance to contamination with extraneous flocculants such as salt, gypsum, cements, solids, etc. It requires amounts of an effective flocculant to induce even a slight shift in the degree of flocculation of the system, and this can be readily corrected with a small counteracting treatment of floc-control agent.

Controlled flocculation state and equilibrium solids. After a shale control mud has been established in a controlled state of flocculation, field practice is normally to add sufficient new water to the system to maintain a constant surface volume of mud. In some cases where the volume of shales drilled is not high, the mud will remain in a low solids state. If, however, massive shales are being drilled, the mud builds up in solids but experience has shown that a self-limiting condition is eventually reached at which time solids cease to accumulate in the mud. This we have chosen to call an "equilibrium solids" condition. In any given well the value of this "equilibrium solids" condition bears and approximate relationship to the calcium level being maintained in the mud. Since calcium ion is a severe flocculant and tends to shift the mud towards the coarse floc state (C of Figure 5), at a given ratio of floc controlling agent, the equilibrium solids tends to exhibit an inverse relationship to the calcium level, i.e., the higher the calcium level, the lower the "equilibrium solids" for a given viscosity and gel level. Figure 6 represents these conditions graphically.

The importance of this relationship is best shown by example. If a well using shale control mud, with a 400-600 ppm calcium level, has been drilling massive shale and has thus reached an equilibrium solids state, then encounters a strong calcium contributing formation, such as anhydrite, the viscosity level will rise. There are two approaches to correcting the situation: either reduction of the calcium level so that the degree of flocculation returns to the original level, or adjustment of the floc control agent and solids to a level compatible with the new conditions. The choice depends solely upon the anticipated future conditions of drilling. If the problem is

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of a temporary character, the first alternative is indicated, but if the condition is just one of a series of anticipated encounters with flocculating formations, anhydrite, salt, etc., the second procedure will prove the most satisfactory and economic.

In most areas, as in the Rocky Mountains and Canada, where gypsum and anhydrite may represent normal problems, shale control muds are usually in a low solid state well below any equilibrium solids level and changes in flocculation state go practically unnoticed.

Controlled flocculation and dispersion. Since the floc controlling agent acts as a dispersant, and the reduction of floc size and partial dispersion will result in lower viscosity and gels, inexperienced personnel might feel that this is a desirable condition to seek. Shale control reagent contain the proper quantity of floc controlling agent should be avoided unless the mud engineer has established that the flocculating environment of a specific system is sufficiently severe to justify supplementary treatment.

This balance between degrees of controlled flocculation and low level dispersion will not basically effect the well bore stability since shale stabilization possesses a time dependency in that infusion of filtrate into the very low permeability shales progresses at a reduced rate. The distortion of this balance shows itself primarily in the short term reaction between mud and cuttings in the presence of severe agitation which in turn is reflected in a loss of some of the ability of the mud to suppress "mud-making."

Table 2 presents a study of how severe this loss of control of "mud-making" can become by promiscuous use of supplemental floc-controlling agent. This study was made on a well drilling the Hackberry shale section which was topped at 9,144 feet. During this entire study, since the calcium-alkalinity relationships were properly controlled, well bore stabilization was maintained this was substantiated by the absence of any well bore difficulty and the high recoveries of well consolidated stable material from sidewall coring of the formations at the close of operations.

This and other studies have substantiated the theoretical reasoning that, even though a system contains a normally considered flocculating agent, if it has been so treated as to yield a

dispersed state, it will be a severe "mud-making" system. If this dispersing state is linked with a non-stabilizing mud chemistry, well bore erosion will result. Whether and how soon this will lead to well bore instability depends upon the character and susceptibility of the formations being drilled.

Shale control mud environment as an effective clay modifier. To substantiate that the chemical environment in a shale control mud is an effective clay modifier, an offset well to the one discussed earlier and using the red limed mud was selected for study. Table 3 presents the results of determinations of the exchangeable sodium on the mud solids in representative samples of the mud system while drilling through the sale section. The composition of the original hole mud varies slightly from the other well but the correlation is very good considering the possible variations in composition due to commercial clay "sweetening," top-hole chemical treatments, and variations in the quantity and character of the mixed shales and sands above the shale section.

From these data it is apparent that the calcium level in this system is highly effective in replacing the sodium from the clays to yield a truly calcium type base mud clay. This clay modification coupled with the floc-controlled mud system explains the observation so often made that "shale control muds all look alike." On the character of the shales drilled, with little or no modification due to the chemicals in the mud, they vary widely in properties from area to area and from depth to depth in a given well.

Table 4 shows a comparison of shale and mud performances of various mud systems based upon a summary of published literature, field performance reports, and selected shale performance tests carried out in the course of this investigation.

This article is based on a paper presented at the Fifth World Petroleum Congress in New York, N. Y., May 1959. —The End

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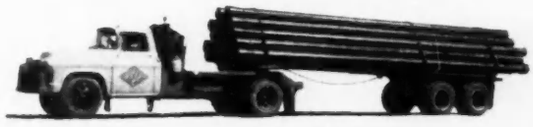

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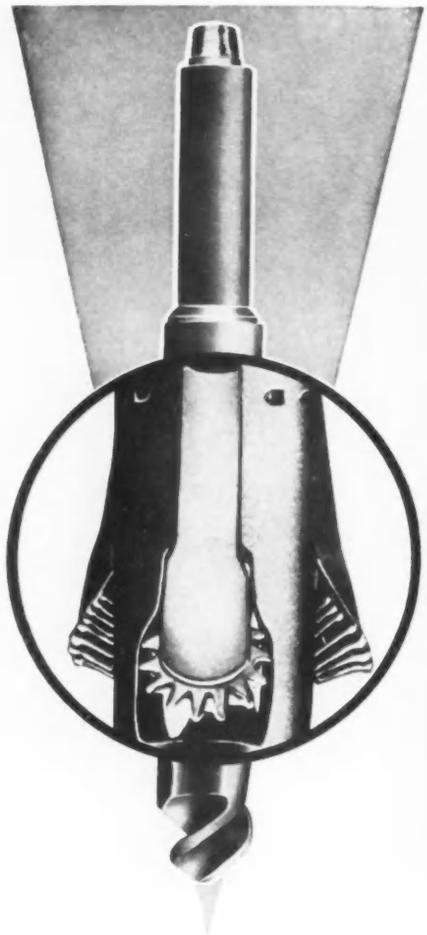

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FIGURE 1—Jamaica offers promising geology and favorable political conditions.

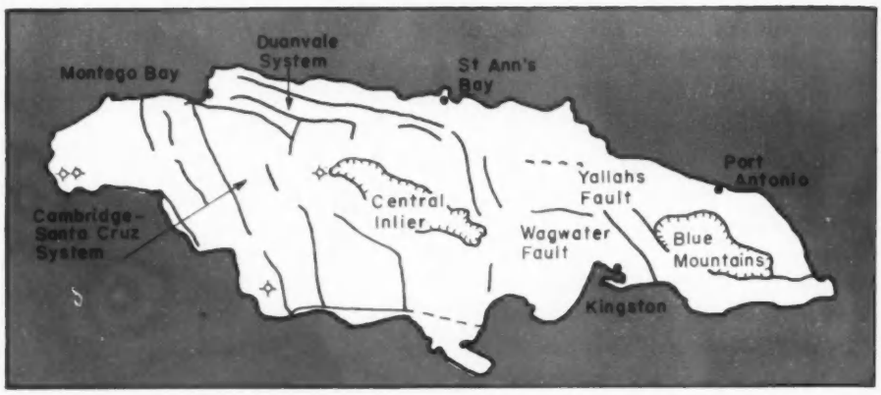

FIGURE 2—Major structural features and the few deep tests drilled in Jamaica.

Renewed search for oil is planned in Jamaica

Geologic sections are promising, numerous surface structures have been mapped, and gas seeps add encouragement

By Edward A. Koester,
Petroleum Consultant, Denver

UNSETTLED POLITICAL conditions in certain Latin-American countries have caused a shift in exploratory interest to other countries with stable governments. Among these is the British island of Jamaica and its surrounding cays. There new geological information, not generally known, is causing oil prospectors to re-evaluate oil and gas possibilities.

This new knowledge of the stratigraphic picture in Jamaica has been uncovered by the Jamaica Geological Survey Department. Its work has only recently been published in annual reports and in "Geonotes" of the local society. Neither enjoys wide distribution among oil geologists.

Previously, Jamaica received little attention from oil seekers, due to the

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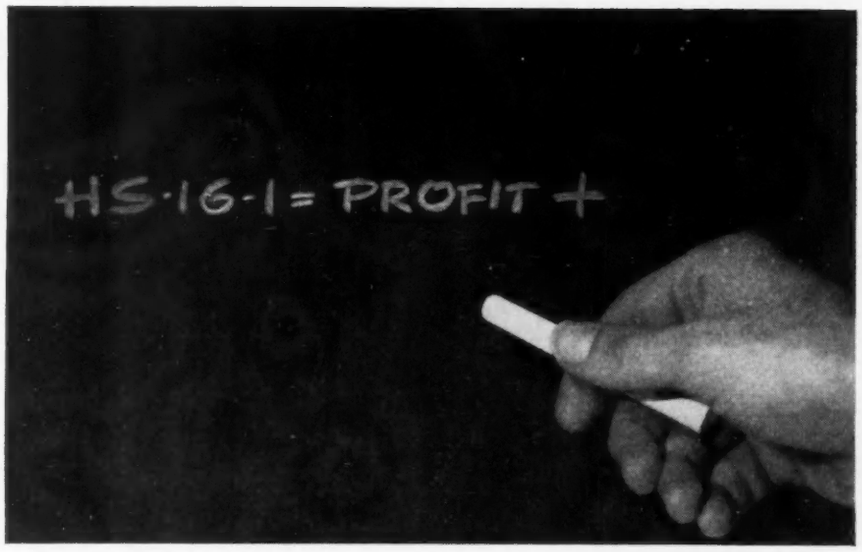

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B2. Circulation with the well head in place, and before setting the packer eliminates wire line work.

B3. The HS-16-1 is easily run in straight or deviated holes.

B4. No difficulty in running the packer into the top of a liner.

C. Setting the HS-16-1 is a simplified operation:

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C2. Design eliminates the possibility of premature setting.

C3. The "hydraulically-set" feature minimizes the problem of spacing out.

C4. Positive well control is achieved since the well head is installed *before* the packer is set or drilling fluid displaced.

C5. Producing zones may be washed *after* the well head is installed.

C6. Set at any depth as no tubing weight is required when setting. Hydraulic setting allows the tubing to remain in tension due to its own weight.

C7. Treating fluid may be spotted across the producing zone before the packer is set.

D. Coming out – the HS-16-1 has two big advantages:

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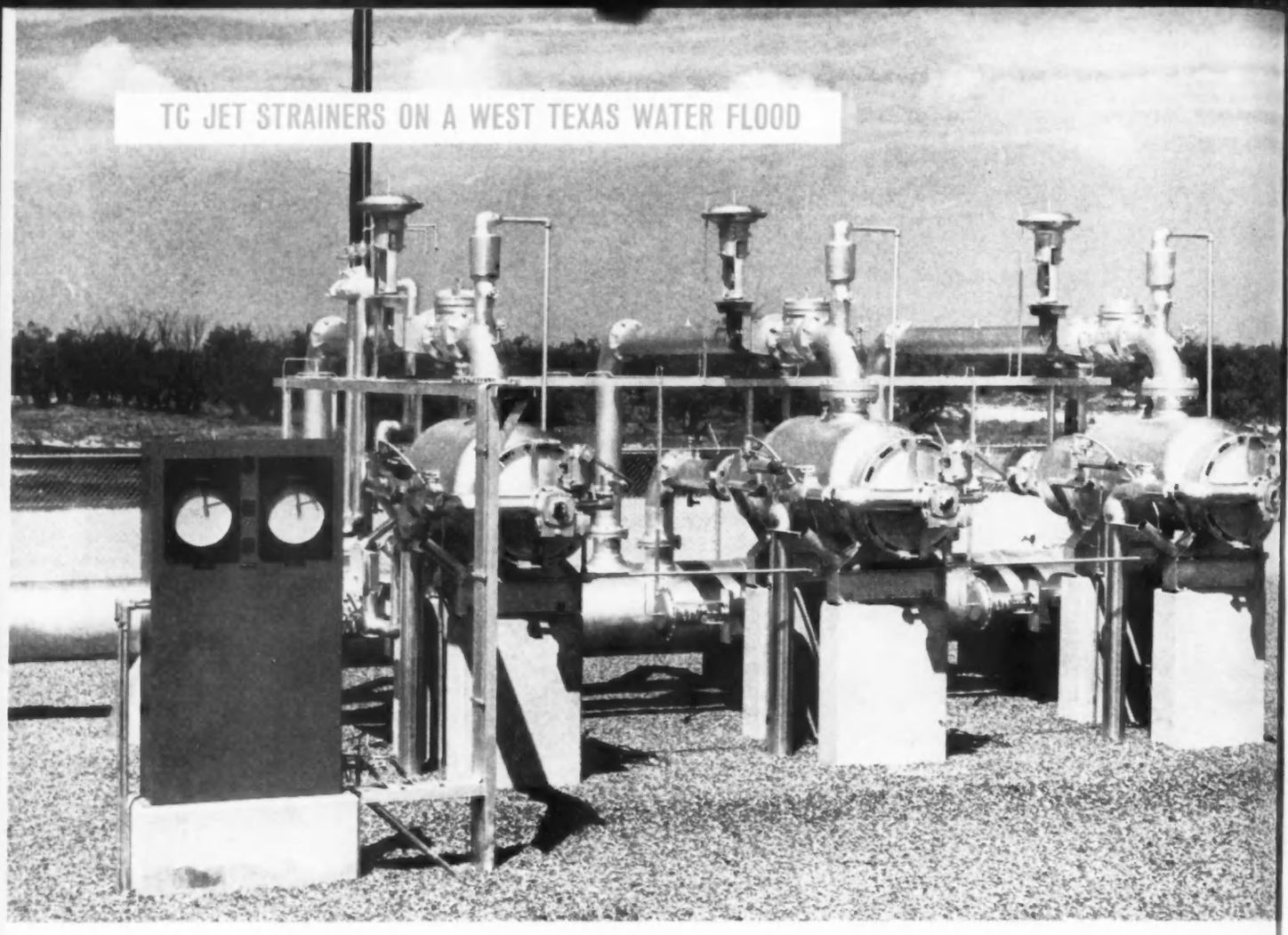

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opinion that it is covered with a relatively thin section of Tertiary and Cretaceous rocks which are largely volcanic in origin and which have been intruded by dikes and sills. This is true of those parts of the island in which the scant drilling that has been done is concentrated.

Oil men now feel that four tests in an area of about 17,000 square miles are inadequate, and that a "new look" is justified by the subsequent geological findings. A live-and-let-live petroleum policy by the government of Jamaica has tended to further add to the attractiveness of this virgin island.

Previous Exploration. A 1,300-foot test by Base Metals Mining Corporation in 1955 and three deep tests by Pan-Jamaican Oil Company in 1957 constitute the total exploratory effort on the island. Seismic work on which these tests were in part located has been described as useless. The favorable stratigraphic section of rocks reported in the first well was not duplicated in the later wells, each of which is believed to have been located too close to the major structural features of the island; hence the better part of the sedimentary section was not found. These tests are in the western third of the island.

But the down-dip, thicker section of Cretaceous marine shales, about which so much has been learned in the past few years, is found in the northern and eastern parts. Dr. L. J. Chubb, a leading authority on the Cretaceous rocks of the Caribbean area, estimates as much as 12,000 feet of sediments may be found. Scores of surface structures are known and more are expected to be found by additional work. None of the tests drilled thus far is near the several gas seeps that have been known for years.

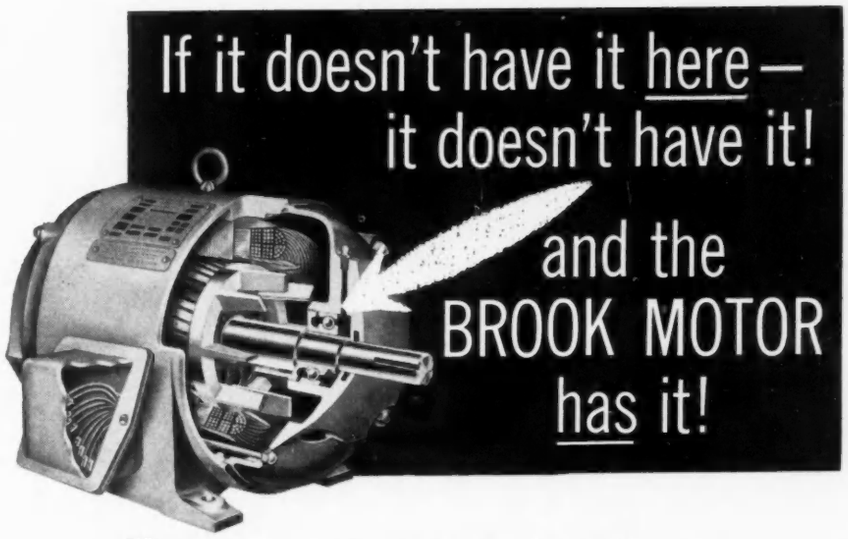
Structure. The major structural features of the island and the deep tests drilled are shown on Figure 2. The Central Inlier (A) is the anticlinal backbone of the island west of the Wagwater Fault. Here Cretaceous rocks are exposed in a feature that has had a long and complicated geologic history. All oil tests have been drilled on the south and west sides of this feature.

Topographically, the highest part of Jamaica is found in the Blue Mountains (B) where peaks rise to above 7,400 feet. This massif was raised up and overthrust along the Yallahs Fault Zone (Y) in Middle Miocene times. East of the Blue Mountains a thick Cretaceous shale section, which needs further study, is found in the Rio Grande Valley, south of Port Antonio. These rocks may be older than any Cretaceous beds in Jamaica, according to Dr. Chubb.

Parallel to the Yallahs Fault is the Wagwater Fault Zone (W), which trends northwest-southeast, except at the south end, where it apparently

TABLE 1—Generalized Stratigraphic Section of Jamaica

Quaternary		Alluvium, beach sands, recent and raised reefs	
Late Tertiary		Coastal Formation and Upper Miocene (Pliocene?)	
Middle and Lower Tertiary		White Limestone Formation (Middle Eocene to Lower Miocene) Yellow Limestone Formation (Middle Eocene) Richmond shales (Lower Eocene) Wagwater Conglomerate (Lower Eocene)	
		Sunderland Inlier	**St. Ann's Great River**
CRETACEOUS	**Maestrichtian**	Garlands-Mocho Series Vaughansfield Series 100 feet Popkin Series 300-600 feet Maldon Series 240-370 feet Woodland Series 325-485 feet Calton Hill Series 180 feet Shepherds Hall tuffs 2,800 feet	
	Campanian	Stapleton Series 125 feet Newman Hall Series 2,000 feet Sunderland Series 2,000 feet Johns Hall conglomerate 500 feet	Shale, w. conglomerate & sandstone in upper part 1,200 feet
	Santonian		Barrettia limestone 15 feet
	Coniacian **Turonian**		"Inoceramus shales" w. conglomerates and sandstone, chiefly in upper third 2,800 feet
Igneous and Metamorphic Rocks		Newcastle Porphyry (Middle-Lower Eocene) Nutfield Volcanics (Lower Eocene?) Granodiorite (End of Cretaceous) Hornfels and Metamorphosed Cretaceous beds Andesite dikes and other intrusions in Cretaceous beds	



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turns east to become a coastal fault. The area between it and the Yallahs Fault Zone is known as the Wagwater Belt, in which a considerable thickness of debris and clastics accumulated in early Eocene time. These are derived from the Blue Mountains on the east and a large mass of granodiorite intrusions on the west.

The Wagwater Fault Zone is also important in that along its projection in Upper Cretaceous times there existed a boundary between two faunal provinces. The eastern section correlates more closely with Cretaceous beds in Cuba, whereas the western section may correlate with those rocks in Venezuela and Colombia.

In western Jamaica, parallel to the main direction of the Wagwater Fault Zone, is the Cambridge-Santa Cruz Fault Zone (C), extending southeast from Montego Bay. The other fault trend is exemplified along the north coast by the Duanvale Fault System (D), which extends east of Montego Bay. It consists of a complex zone of faulting, which steps down the land surface and the bed of the sea to the depths of the Cayman (Bartlett) trough, separating Jamaica from Cuba. A similar fault system is found on the south coast.

That these old lines of weakness and structural deformations are still alive is demonstrated by the fact that the epicenter of earthquake activity as late as the tremor in 1957 was located along the trend of the Duanvale system west of Montego Bay.

Small structural features, not shown on the map, which would be the site of oil exploration, are generally parallel to either the east-west of northwest-southeast trends. None of these structures on the north and east side of the island where stratigraphic conditions are believed to be better have been tested.

Stratigraphy. More than half the surface of Jamaica is covered by the "White Limestone," which ranges in age from upper Middle Eocene to Lower Miocene. The underlying "Yellow Limestone" occupies a much smaller surface area and is of Middle Eocene age. Below it in some parts of the island are the "Carbonaceous shales" (Richmond Beds) of Middle and Lower Eocene age, which have been mistaken in some areas for Cretaceous shales, and vice versa. Tuffs and conglomerate make up a good part of the Tertiary section in several areas, and are sometimes found interbedded with the above formations.

Outcrops of Cretaceous rocks are present in the Central Inlier and on the flanks of the Blue Mountains. In the latter area they are just now being thoroughly studied, and are believed to represent the oldest Cretaceous of the island. Moreover, Cretaceous rocks are found in several inliers, particularly southeast of Montego Bay, near St. Ann's Bay, at Guy's Hill inlier between the Wagwater Belt and St. Ann's Bay, and elsewhere. The nature of the stratigraphic section in these inliers has only recently been understood.

Late Tertiary and Pleistocene deposits are found in bands of variable width along the edge of the island.

Karst topography is a characteristic of the Tertiary limestones in all parts of the island. But it has reached an advanced stage of development in the "Cockpit Country," which lies north and west of the Central Inlier. This

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area, being much dissected by deep sink holes, presents a very rough topography, very difficult to traverse. Due to the intense solution of the limestone by atmospheric waters, rain water sinks into the fissures and cavities forming large caves and conduits. Relatively few surface streams are developed, and water supply in these areas is a serious problem. Naturally, seismic work in these areas is very unreliable.

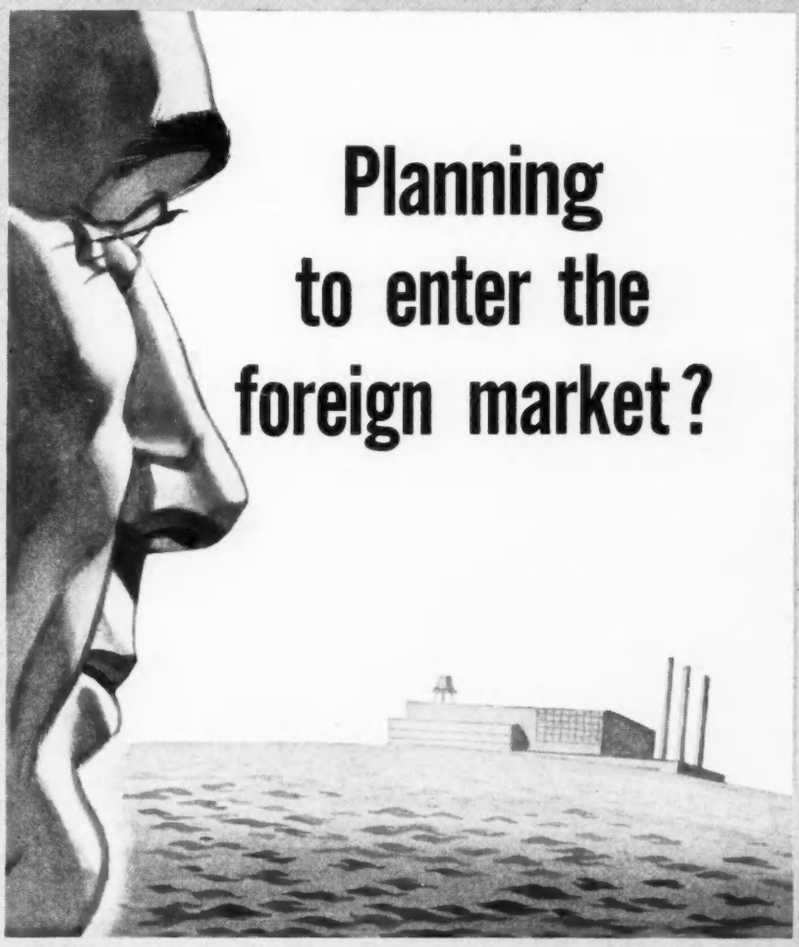
The stratigraphic section shown in Table 1 (page 177) is compiled from the later publications of the Jamaica Geological Survey. The Tertiary section is fairly well understood, but much work remains to be done on it. In some areas the White Limestone has been successfully broken down into individual formations. But the relationship of these formations to each other and to the Richmond shales[1] will be studied more thoroughly.

Considerable progress has been made in the understanding of the Cretaceous beds, particularly in the last few years. However, more field work is needed to determine the relationships of the sections exposed in the several separated inliers; and undoubtedly this work will change the interpretation shown in Table 1, which is an attempt to illustrate the relationships found in two inliers that give long sections.

The Sunderland Inlier[2] is southeast of Montego Bay. The St. Ann's Great River section[3] near the north coast, is on an undrilled anticline where methane gas bubbles continuously from the Windsor Spring. Earlier work had suggested that these two sections were correlative. Micropaleontological studies have shown that the rocks at St. Ann's are older than those found at Sunderland.

Moreover, the lithologic character of these rocks is more attractive to the oil finder than those exposed at the Central Inlier. The latter section is that which was penetrated in part by the four wells previously drilled on the island. Moreover, the Cretaceous beds east of the Blue Mountains may be older than those at St. Ann's. They are presently being studied by geologists of the Survey under the leadership of Dr. V. A. Zans.

Exploration. Jamaica Time Petroleum, Inc., headed by R. R. Greenbaum of Wichita, Kan., signed an agreement on Sept. 22, 1959, with the Jamaican government for an exclu-



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sive exploration concession covering all of Jamaica and its territorial waters, as well as the Pedro Banks and the Morant Cays. The terms of the concession are realistic, and allow for a thorough program of geological and geophysical exploration ahead of the drill, rather than the hasty program usually demanded in so many concessions.

Jamaica Time is allowed 18 months to do geological work in the area before the first of a series of five wells must be commenced. One of these tests must be drilled to 15,000 feet, if possible, but there is a "granite clause" in the agreement. Moreover, all geological and geophysical informations secured by the earlier operators in the country, including sample and electric logs and geophysical surveys, are available to Jamaica Time's geologists, who are now working in the country.

Other features of the concession are attractive. Royalty is sixteen and two-thirds percent. The term of the mineral leases to be given will be 20 years, with right of renewal for another 20 years. No rentals are payable for the first five years after the acreage is chosen, and thereafter the rentals are nominal.

A checkerboard system similar to that of Canada is provided, except that the retained units are larger. Acreage is earned on a graduated scale, with wells drilled below 1,000 feet earning 40,000 acres and those going over 12,000 feet acquiring 80,000 acres. If oil is found above 1,000 feet, the discovery well earns 40,000 acres. Any disputes that may arise are to be settled by impartial arbitration.

The search for natural resources in Jamaica commenced in 1494, when Columbus landed, looking for gold. Nearly 450 years later the red earth above the White Limestone was found to run high in alumina, and today Jamaica ranks at the top among the bauxite-producing countries of the free world. This industry offers a profitable market for any gas that may be found. Meanwhile, the search for the Black Gold of the 20th century continues, encouraged by the more favorable geological knowledge uncovered in recent years.

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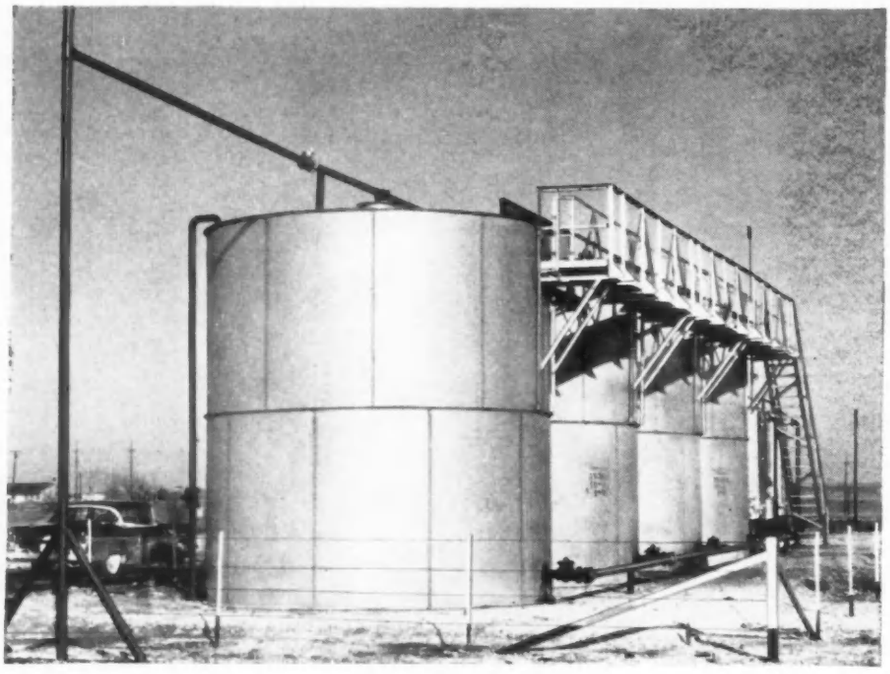

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About the Author

Dr. Edward A. Koester, petroleum consultant and geologist, Denver, is a past president of the American Association of Petroleum Geologists (1954). He was graduated from Friends University, Wichita, Kansas, and the University of Missouri. He also studied at the University of Colorado. He worked with the U.S. Geological Survey and several independent companies from 1929 to 1947, and then became a consulting geologist and oil producer.

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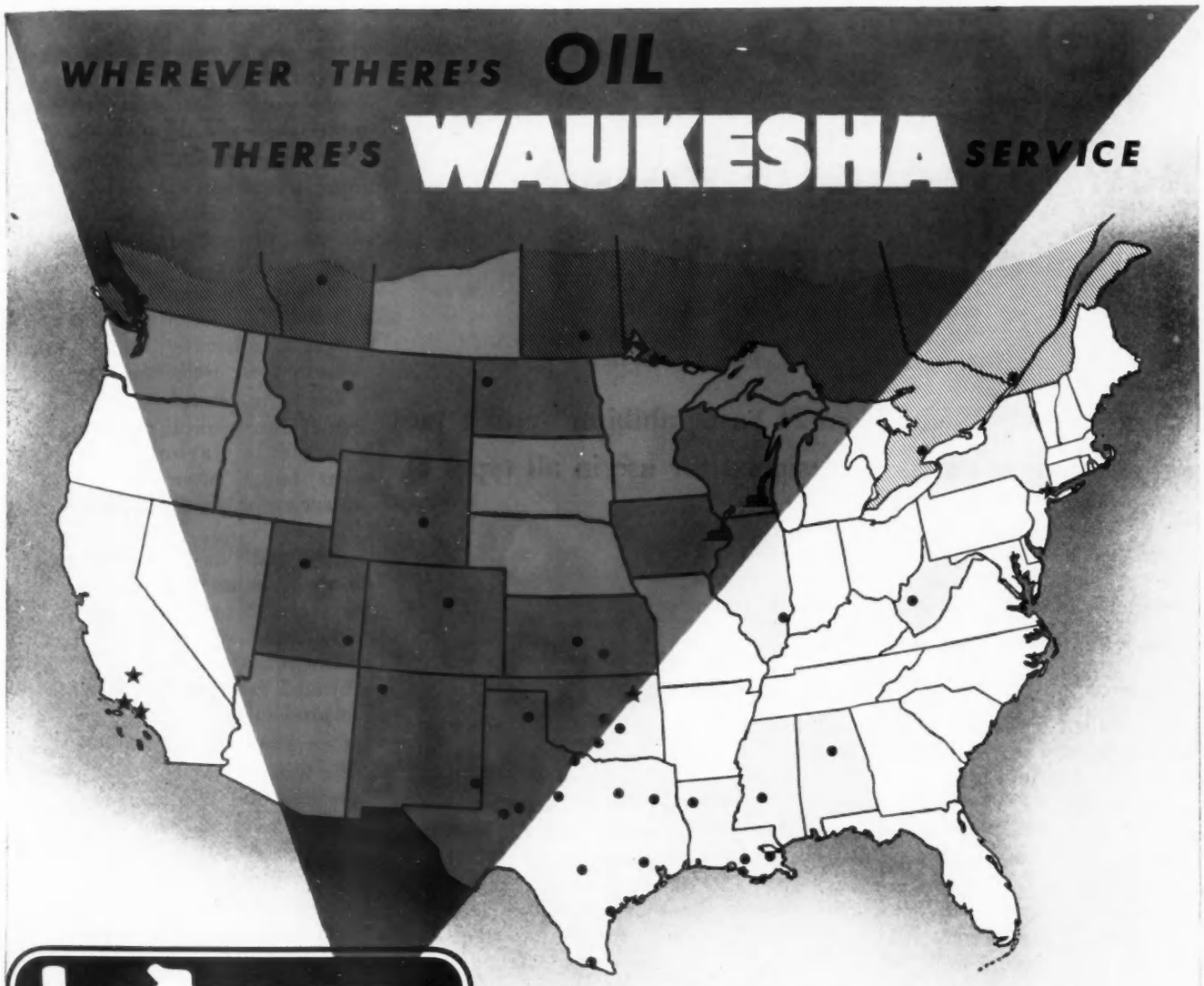

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How to reduce downhole corrosion with inhibitors

Operators may choose from 21 basic inhibitor application methods. Treatments are designed for use in all types of wells

By Jack P. Stanton, Manager of Corrosion Control,
Visco Products Company, Houston

DOWNHOLE CORROSION cuts production, reduces profits and causes expensive equipment replacement and workover costs. Properly applied inhibitors have been found effective in reducing the corrosion problem in the various types of flowing and artificial lift wells. This article will discuss corrosion problems encountered in oil and gas producing wells. Also included are 21 inhibitor application methods which can be used to solve these problems.

TYPES OF CORROSION

Corrosion in sweet oil flowing wells results from electrochemical, galvanic, electrolytic, erosion-corrosion and stress corrosion attack. *Sweet oil pumping wells* are subject to the same types of corrosive attack. Sucker rods may become pitted or develop stress-corrosion cracks. Pin and coupling failures and rod and tubing wear are major trouble sources. Rod and tubing wear appears to result from corrosion-erosion wherein moving rods rub off the protective corrosion products. This problem can be particularly severe when produced fluids carry sand. Oxygen corrosion also occurs in such wells, the oxygen being introduced when wells operate with an open annulus and low fluid level.

Corrosion problems are increased in *gas lift wells* because of depth and consequent high bottom-hole temperatures, low bottom-hole pH's and excessive water production. Corrosion factors, in addition to those listed previously, include: electrochemical corrosion of the differential gas concentration type which is evidenced by a spongy, porous appearance of the affected area; galvanic corrosion of steel gas-lift mandrels in contact with monel valves; and corrosion-erosion of the interior of the mandrel.

Tubing corrosion generally is more severe above gas lift valves. Oxygen corrosion sometimes is encountered in sweet gas lift wells. If the lift gas compressor exerts suction on the well casing, air is introduced each time a well is pulled. Paraffin and corrosion problems frequently exist simultaneously in these wells.

Sweet gas-condensate wells experience electrochemical corrosion, which is caused by carbon dioxide and water, and is often aggravated by presence of short chain aliphatic acids (formic, acetic). Formation of deep, sharp-edged pits is common and is more severe in the upper portion of the string where condensation of acidic water occurs. In fact, corrosion of Christmas tree fittings are usually subjected to more severe attack than the producing string.

Corrosion-erosion is common in these wells because of relatively high flow velocities. The problem is particularly acute in high-volume producers. This type of attack is most in evidence when turbulance adds to the corrosion product removal action. It appears on the downstream side of chokes, valves and producing string joints. A special kind of galvanic attack known as ringworm corrosion sometimes occurs a few inches above and below tubing upsets. Normalizing at the pipe mill will relieve this problem.

Most of the aforementioned types of corrosion are found in *sour gas condensate wells.* However, the primary problem in deep, high pressure wells is with sulfide stress corrosion cracking. Severe cracking has been encountered with metals stressed at

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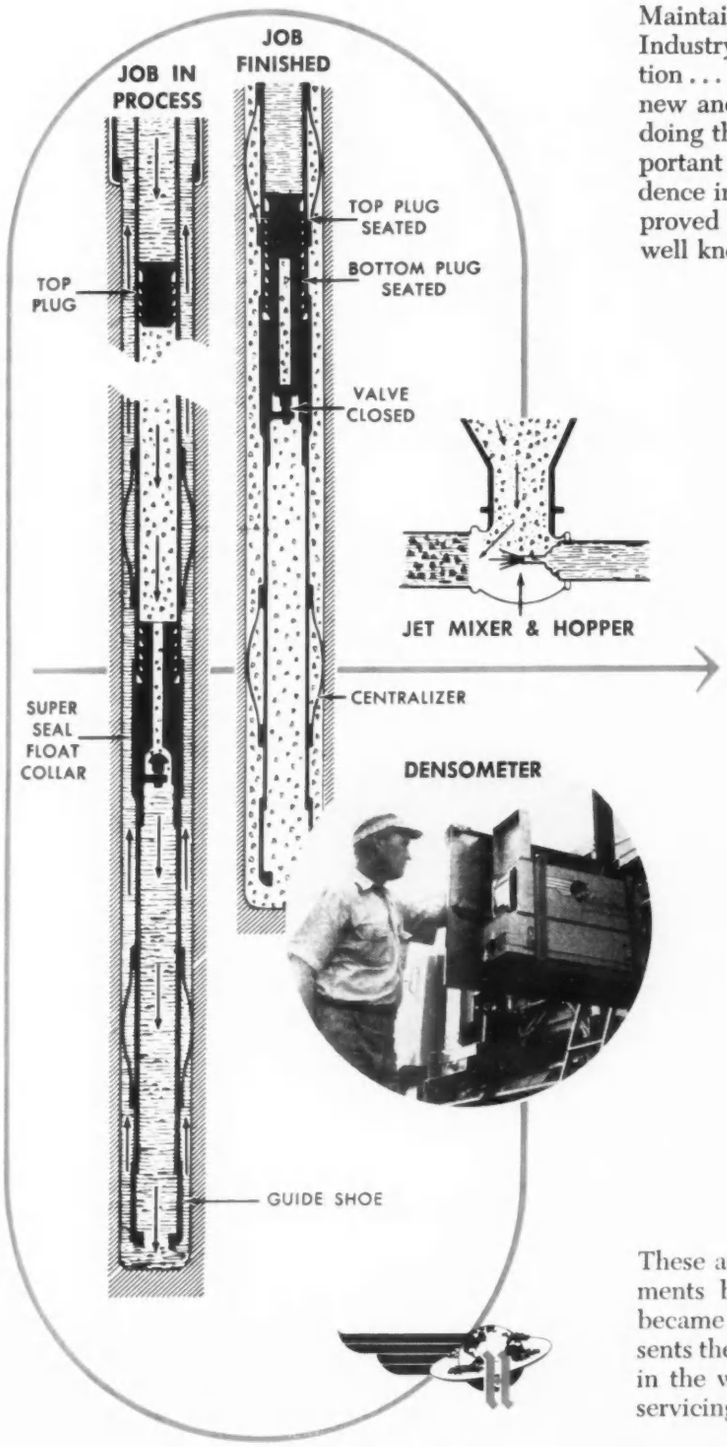

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only 25 percent to 75 percent of yield strength. High strength steels and alloys used for completion of such wells are especially susceptible. Ruptured members are characterized by presence of a smooth plane on most of the rupture surface, with an uneven, torn portion on one side.

Sour pumping wells are subject to electrochemical, sulfide stress corrosion cracking, corrosion-erosion, embrittlement and blistering, microbiological, annular space condensation, oxygen, galvanic and electrolytic corrosion.

Electrochemical attack is due to presence of sulfides and water and is accelerated by carbon dioxide, organic acids and/or oxygen. Embrittlement and blistering appear closely related to sulfide stress corrosion cracking. Monatomic or "nascent" hydrogen produced in the corrosion reaction, migrates through the steel and converts to the diatomic gas at occlusions in the metal. Pressure builds up at these gas-gathering points until internal rupture of the metal occurs.

Microbiological corrosion results from action by sulfate-reducing bacteria. These microorganisms, present in earth, grow and multiply only in a suitable oxygen-free (anerobic) environment in which moisture, trace minerals, organic matter, suitable pH and reducible sulfate ions are available.

The sulfate-reducers cause corrosion by producing acidic, corrosive H_2S and by comsuming hydrogen formed at the cathodes in the downhole corrosion cells. By removing the polarizing hydrogen layer, they reduce resistance in the corrosion cell and accelerate the attack.

Annular space condensation occurs because the upper part of the casing is cooler than the dewpoint of the gas in the annular space. Water droplets which form are acidic and corrosive. The iron sulfide scale thus formed is cathodic to the steel and encourages pitting. This type corrosion may be overlooked since the same attack usually does not occur on the outside of the tubing. Generally, even the upper part of the tubing is above the dewpoint of the gas in the annulus.

Oxygen corrosion sometimes is encountered in sour pumping wells with a low fluid level and open annulus.

Galvanic corrosion and electrolytic corrosion also are encountered. Apparently, the lubricant film on polished rods can insulate the rods from the tubing and casing. Thus, stray currents can enter the pumping unit and rods and jump to the tubing somewhere downhole. The current jump usually occurs just above a high-resistance joint in the rod string. The thread lubricant in the joint presumably furnishes most of the resistance.

CORROSION PROBLEM SOLUTIONS

Table 1 lists various solutions which may be applied to the corrosion problems discussed previously. While this article is concerned primarily with application of downhole inhibitors, the importance of the nature of the corrosion problem and the alternative solutions shown in Table 1, must be emphasized. Selection of the type chemical and application method, and evaluation of results, should be based upon thorough knowledge of the problems and alternative solutions. Sometimes situlations are encountered wherein no inhibitor can do the job until necessary engineering changes are made.

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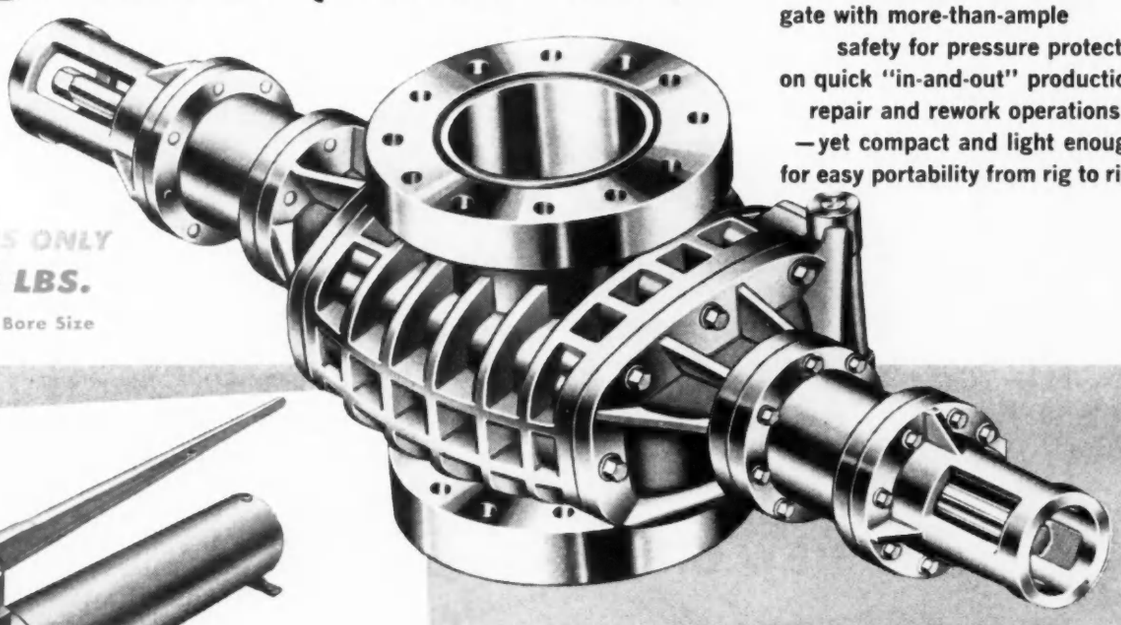

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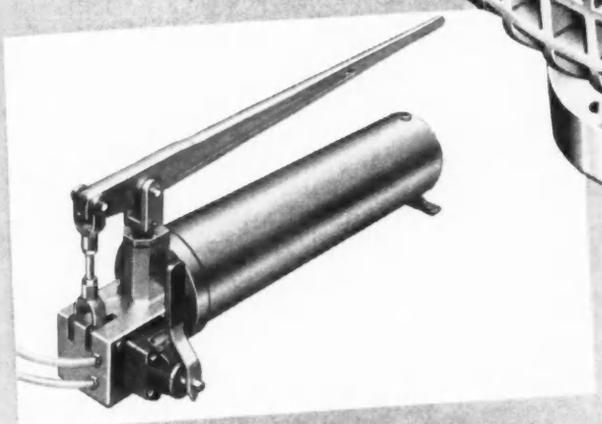

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To further speed up installation and break-out operations, you don't need a power-driven hydraulic system to operate the Type LWS. You can use one, of course, and various power driven systems are available for closing the Type LWS in from 2 to 7 seconds, depending upon the arrangement used.

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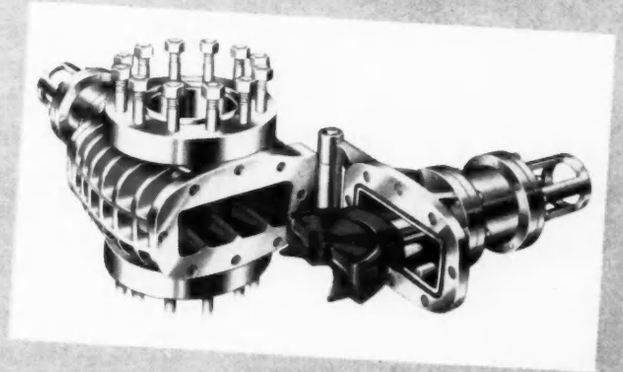
EASY RAM ACCESSIBILITY

You'll also like the "Swinging *End*-Opening" design that permits you to change rams or service the ram compartment *without breaking hydraulic connections or losing operating fluid.* (*See open view below.*)



Other Type LWS advantages include positive **"In-Line" Piston and Ram Design,** with no yokes, levers or complicated connections between each ram and its operating piston... **Quick-Draining Ram Compartments** with rams traveling on guide ribs high above any sand or mud accumulations... and still other pressure control advancements developed by Shaffer, the industry's leader in well pressure control equipment.

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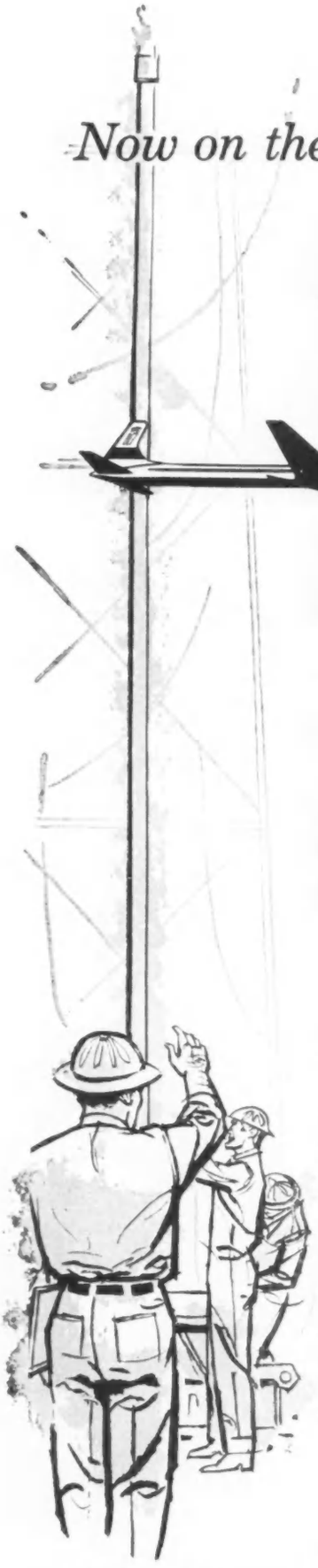

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corrosion problem can best be handled by application of a corrosion inhibitor, the inhibitor type and treating technique must be selected.

Inhibitor types include organic film formers, usually cationic in nature although nonionics frequently are included; inorganic film formers, usually anionic; neutralizing agents, usually basic-reacting inorganics; and "vaporizing" chemicals, usually low boiling nitrogen derivatives. Of course, inhibitor choice has an important influence on the selection of an application method.

Relative evaluation of application methods is made on the basis of the above considerations along with individual well factors, such as type completion, nature of produced fluids, production practices, etc.

Twenty-one important treating methods now are used to control downhole corrosion in all types of oil and gas wells. Details of each of the methods including advantages and disadvantages are as follows.

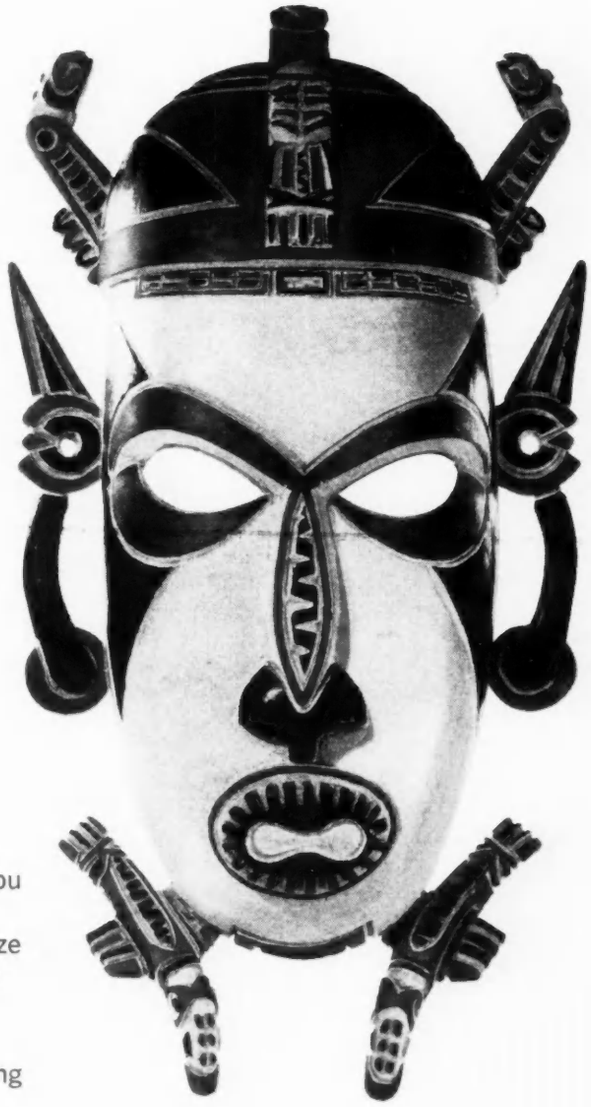
1. Continuous pumping of inhibitor down the annulus. Feed is reliable and only infrequent attention is required. A chemical pump is used to feed inhibitor into the casing. Rate of feed usually is controlled by fluctuations in bottom-hole pressure rather than by the pump rate. Also, no high-volume fluid wash is added to insure that inhibitor gets to bottom.

2. Batch lubrication or hand-dumping inhibitor down the annulus. No equipment is required and efficient use of the chemical is obtained, since circulation can be employed. The inhibitor must have "persist-

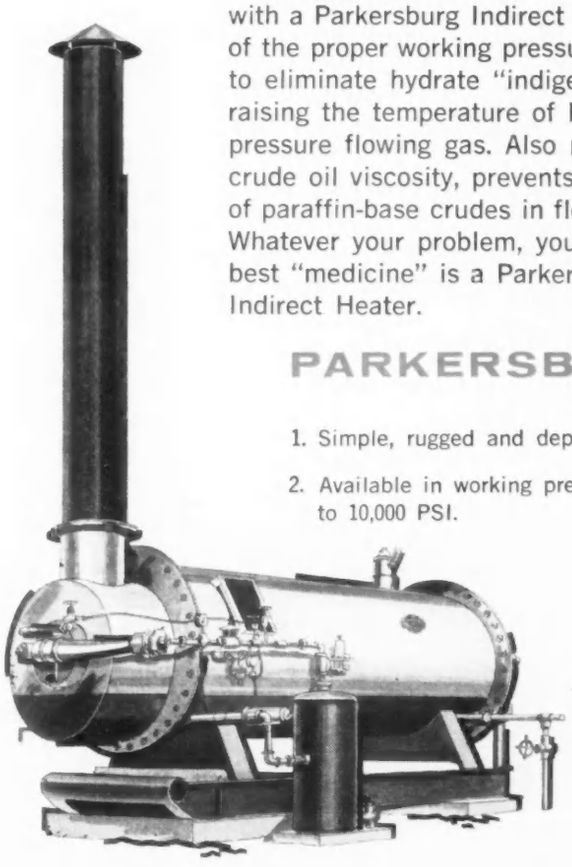
TABLE 1—Available Solutions for Downhole Corrosion Problems

A. Metallurgical:
  1. Careful selection of steels.
  2. Use of alloys.
  3. Stress-relieving or normalizing.
  4. Avoidance of galvanic effects.
B. Electrical:
  1. Cathodic protection
    a. External casing.
    b. Heater-treaters and tanks.
  2. Sacrificial anodes.
  3. Flow line insulators
C. General Engineering:
  1. High pump settings.
  2. Use of sucker rod guides.
  3. Annulus pumping.
  4. Use of rod rotators.
  5. Well-balancing.
  6. Avoidance of pumping rates which produce resonant vibration in the rod string.
  7. Tubing anchors.
  8. Annulus sealing.
  9. Selection of pump types and sizing of pumps and rods.
D. "Permanent-type" protective coatings.
E. Bactericides and bacteristats.
F. Inhibitors.

"INDIGESTION AID" for high-pressure flowlines



Let your Parkersburg man be your "medicine man" in treating hydrate formation problems. He can provide you with a Parkersburg Indirect Heater of the proper working pressure and size to eliminate hydrate "indigestion" by raising the temperature of high-pressure flowing gas. Also reduces crude oil viscosity, prevents congealing of paraffin-base crudes in flowlines. Whatever your problem, your best "medicine" is a Parkersburg Indirect Heater.



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ency" since usual practice is to treat the well only once or twice per week.

3. Batching inhibitor liquid down tubing while the well is shut in. Packed-off wells are treated easily and little or no equipment cost is entailed. However, long shut-in time-for-fall usually is involved. The method is virtually impractical if there is a fluid level in the tubing.

4. Pumping inhibitor to bottom through a macaroni string strapped to tubing. Packed-off wells can be treated, and the operator is assured that chemical gets to the bottom in the prescribed dosage. The string can be installed only when the well is being worked over. This type installation is expensive, easily damaged whenever tubing is pulled and can be installed only on completion or workover.

5. Inhibitor injected through a concentric tubing string. Production is through the small I.D. inner string, and inhibitor liquid is pumped down the annulus between the two tubing strings. The well need not be shut-in for treatment and the operator may check to be sure that inhibitor is getting to bottom. In addition, the installation is nearly automatic. Because of the additional string, installation cost is considerable. Also, increased linear flow velocity in the small string aggravates corrosion.

6. Introduction of liquid inhibitor by wireline dump bailer. "Persistent" inhibitor concentrates ranging from 50-75 percent active are used. The operator is assured that inhibitor gets to bottom, and shut-in time is short (usually less than one hour). However, wireline service may not be readily available and tubing must be full opening to bottom.

7. Free-falling chemical dumping tool. The tool returns to the surface and is retrieved when the well is put back on production. Application costs are low, but it is possible for the tool to hang-up in the tubing.

8. Bottom-hole chemical injector valve. The annulus is filled with inhibitor solution, and inhibitor is displaced through the valve by pumping additional chemical into the top of the annulus. The well can be treated without being shut-in; however, the valve may stick or clog if the annulus is dirty or inhibitor is thermally unstable. Also, the entire

For more data on advertised products, use Readers' Service Cards, last page.

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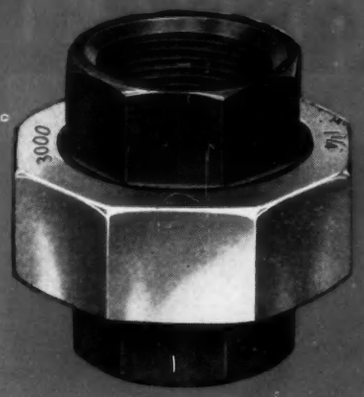

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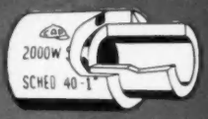

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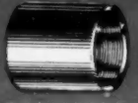

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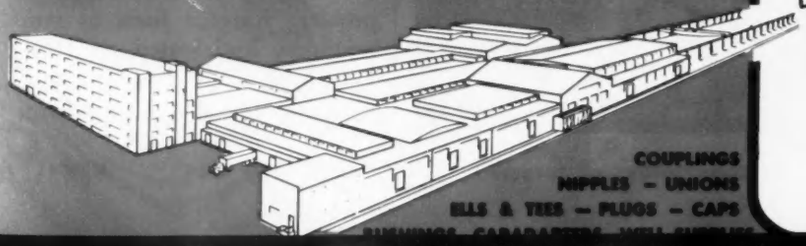

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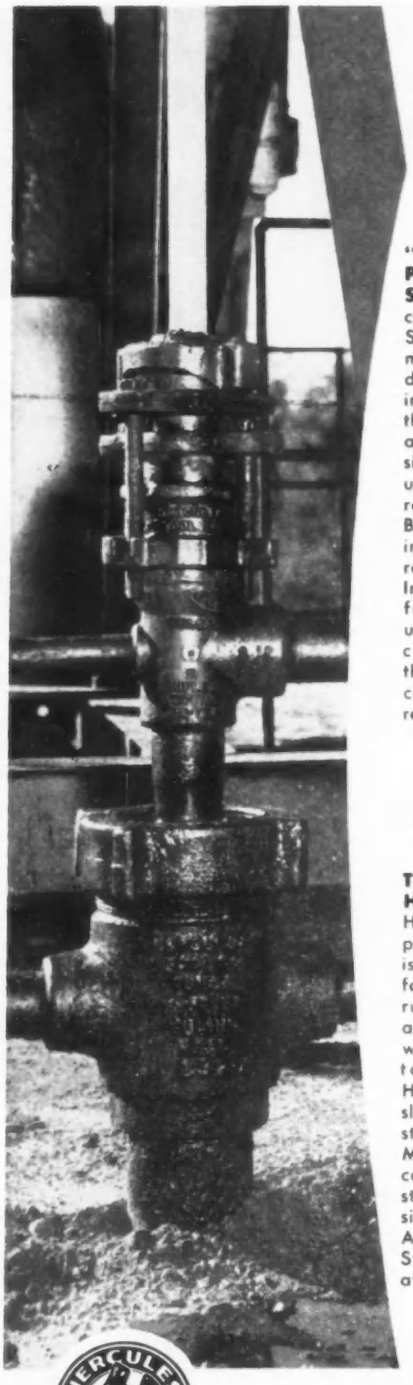
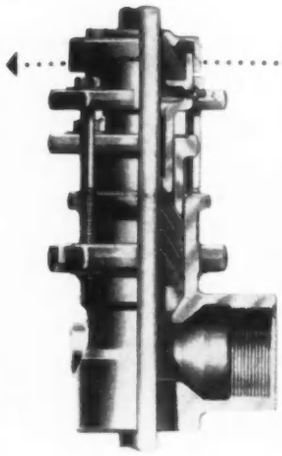
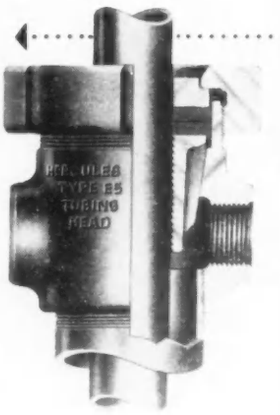


A typical set-up is shown below in Creek County, Oklahoma, using Hercules "Tee Type" Duplex Polished Rod Stuffing Box and Type "E5" Tubing Head. This is an easily assembled, effective and economical producing unit.

"TEE TYPE" DUPLEX POLISHED ROD STUFFING BOX—A combination Tee and Stuffing Box with female thread to screw directly onto the tubing, eliminating one threaded connection and resulting in a considerably shorter hookup. With internal parts removed, the Stuffing Box body is full opening and need not be removed to pull rods. In addition to being furnished in the most used sizes, special combinations of threads and outlets can be furnished on request.



TYPE "E5" TUBING HEAD—This Tubing Head is ideal for any pumping situation. It is economical enough for shallow wells and rugged enough for any depth well, with working pressure up to 1500 pounds. Hercules self-aligning slips suspend the inner string in this Head. Mandrel suspension can be furnished instead of slips, if desired, at no extra cost. A neoprene Tubing Stripper Unit is also available.



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annulus must be filled with inhibited fluid before treatment begins.

The inhibitor used should have powerful detergent properties and be thermally stable at temperatures up to 300° F for period up to two months.

9-10. Dumping of sticks, pellets and/or lumps down tubing. Treatment frequency usually is two-three times per week. Long lubricators installed at the wellhead permit dumping of several sticks at a time. These heavy solids have a good opportunity to get to bottom and little equipment expense is involved.

Disadvantages include: well must be shut-in for a relatively long period, tubing stops or storm chokes cannot be used, partially dissolved sticks may plug chokes and produced fluid may by-pass the solids if the well has a sizeable bottom hole cavity or dead-space.

Some operators use wireline tools to hold sticks on bottom while they dissolve. Also, special "listening" techniques can be useful in insuring that sticks reach bottom.

11. Dumping of pellets or lumps down the annulus of a well without a packer. Chemical usually is added two or three times per week. This is an effective means of insuring that chemical gets to the bottom of an annulus with a high fluid level. However, narrow annulus wells cannot be treated because the pellets bridge. Produced fluid may by-pass pellets or lumps if the well has a sizable bottom hole cavity or dead-space, and partially dissolved pellets possibly could foul pumps.

12. Squeezing chemical into the formation. Although results vary, a continuous formation feedback lasting 3-12 months should be provided each time a well is squeezed. An overflush of oil is used to insure that inhibitor is moved back into formation. A pump truck is employed. This method is used successfully to treat wells which are packed-off or have high fluid levels, and are difficult to treat by other means.

It is not always possible to obtain the desired "life" from a squeeze, and emulsion-blocks or reverse-wetting may develop in some formations. This problem has not been as serious as originally anticipated.

Plugging effects of amine-derived inhibitors on water-wet cores have

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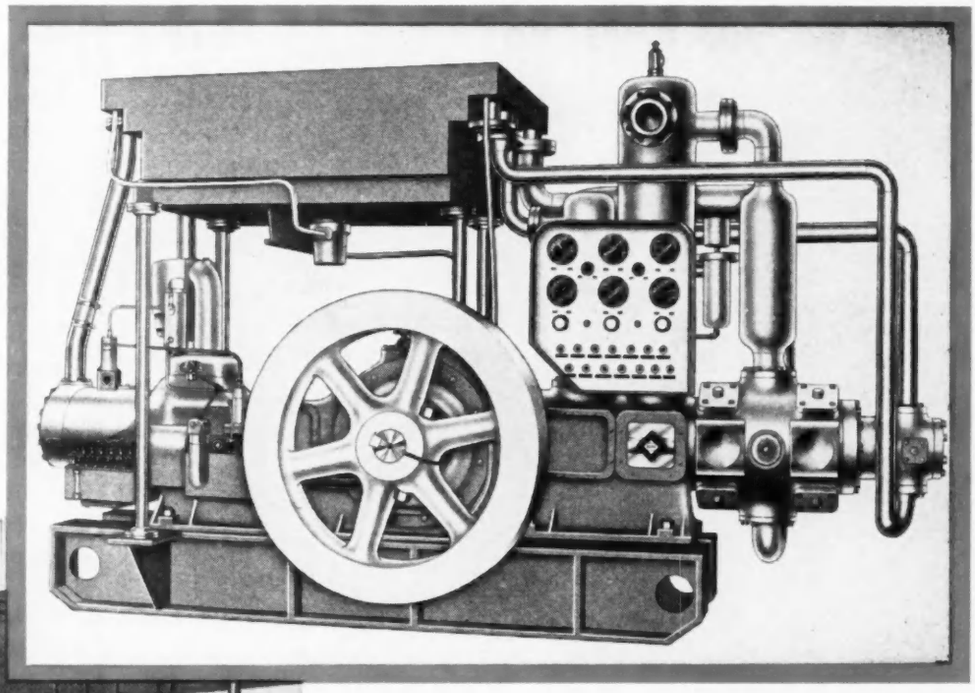
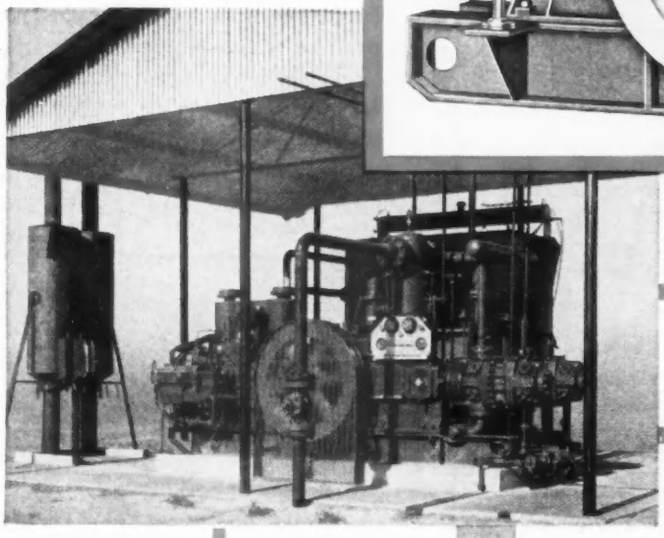


Shown above — the new DPC-60
Single Cylinder Engine-Compressor



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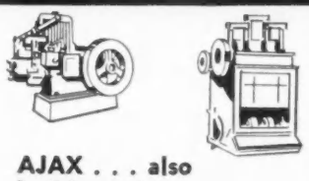

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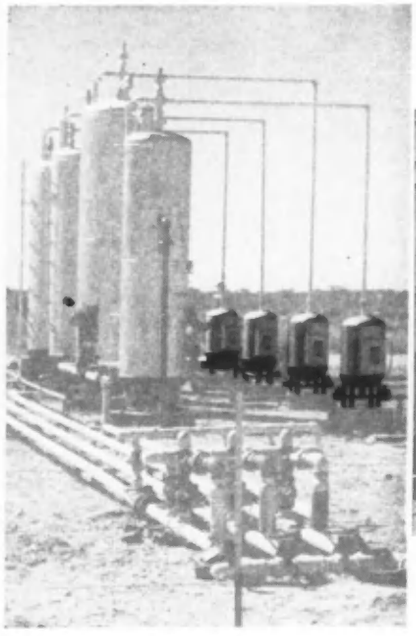
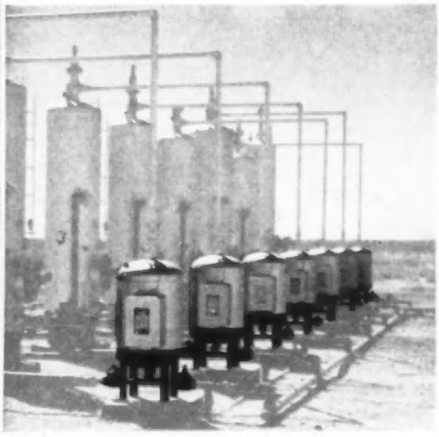


◀ METROL Model 10-CV-01 Vol-U-Meters metering and commingling oil from four separate royalty interests into a common tank battery.



▲ METROL 10-CV-01 Vol-U-Meters metering and commingling oil from seven dual completed wells into a common tank battery.

METROL® "CV" VOL-U-METERS® are designed for accurate metering of crude oil and water by cyclic accumulation, isolation and discharge of equal volumes.

METROL "CV" VOL-U-METERS are available in standard sizes, ¼, ½, 1, 2, 5, 10, 20 and 30 barrels per dump. Standard working pressures are 125, 300, 600 and 1200 psi. Capacities are shown in table below.

Metering accuracy of METROL "CV" VOL-U-METERS depends on proper liquid level control and proper valving, both of which are obtained and maintained. Accuracies of 99.99% are common. This accuracy is attributed to the vessel's patented snap-acting pilot mechanism.* Pilots used on VOL-U-METERS are reliably accurate and react at exact preset upper and lower levels. VOL-U-METERS are approved by most regulatory bodies for measuring oil for royalty and tax payments, testing wells, and commingling oil.

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Accurate metered volumes, low maintenance cost, trouble-free operation, efficient and accurate handling of production, increased field safety, and additional lease automation are among advantages provided by METROL "CV" VOL-U-METERS.

UNIT MODEL NO.	2½ CV	5 CV	10 CV	20 CV	50 CV	100 CV	200 CV	300 CV
Volume per dump, Bbl.	¼	½	1.0	2.0	5.0	10.0	20.00	30.0
Metering Capacity BPD								
Rated	300	500	720	1,440	2,000	4,000	8,000	15,000
Maximum	500	650	1,200	1,800	3,000	5,000	12,000	20,000
Avg. Expected Metering Accuracy, Percent	99.80	99.90	99.95	99.97	99.98	99.99	99.99	99.99

Every Unit is completely assembled, pressure tested, calibrated, and performance tested before shipment.

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been determined in laboratory work as being directly proportional to the molecular weight of the amines.

Questions also have been raised as to whether the primary benefit of a squeeze is derived from long exposure of the tubing to extremely high dosages of inhibitor-in-oil or from the long-term trickle of inhibitor at low dosage back into the tubing from the formation. A near-future squeeze with a radioactively-tagged inhibitor should provide answers to these questions.

13. Automatic applicator. The applicator adds a prescribed amount of inhibitor to the annulus at timed intervals. A flush of a prescribed amount of lease water or produced fluid then follows. Pumper and contract services are not required and small amounts of chemical may be added to low fluid level wells at frequent intervals in which adequate circulation is not permissable. This method is attractive on inaccessible location.

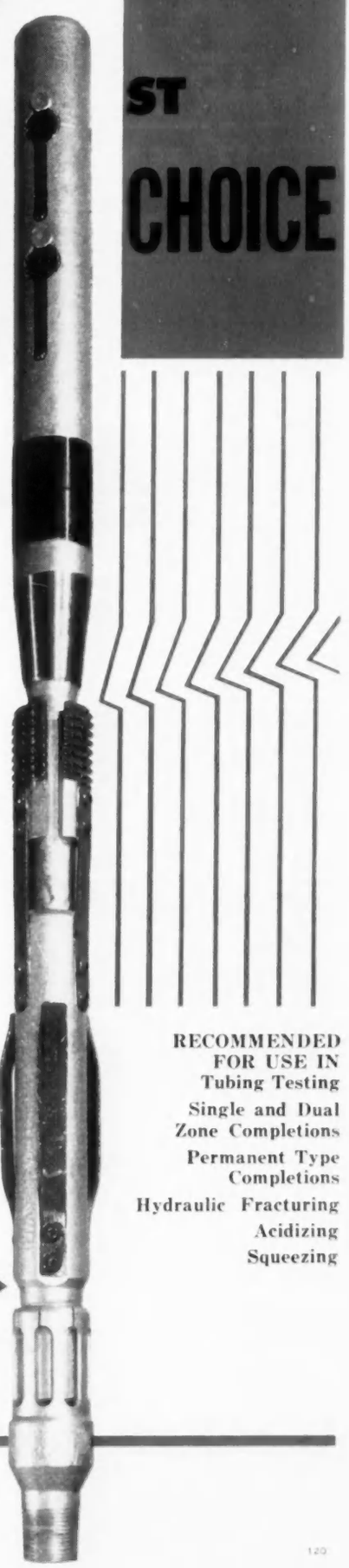
Disadvantages include applicator expense, the probability that present

About the Author

Jack P. Stanton was educated at Central YMCA College and The University of Illinois. He was employed by The Pure Oil Company in 1943, and worked in research and producing operations. He served both as assistant superintendent in gasoline plant operations in West Texas, and as a resident chemist in Pure's sulfur recovery-gasoline plant operations in Wyoming. In 1950, he joined Commercial Testing and Engineering Company as manager of the Oil Testing Department. He joined National Aluminate Corporation in 1952 as a petroleum chemist, later becoming manager of new products application. In 1956, he was transferred to Visco Products Company, where he presently is manager of corrosion control.

MAKE T I W AH PACKER YOUR 1ST CHOICE

for conventional or TUBINGLESS COMPLETIONS



TIW has designed the NEW Type A H Packer for use in both conventional and TUBINGLESS methods of well completion, where small sizes of casing and/or production tubing are used.

Featuring the famous T-I-W Automatic Bottom, which eliminates left hand rotation of tubing while setting or releasing, the A H Packer can be furnished with or without hydraulic hold-down slips.

Available for use with 2⅜" and 2⅞" OD casing, the A H Packer can be set, released and re-set without affecting the efficiency of the packer. One piece mandrel and ring type packing elements provide positive seal against high pressures.

T-I-W has pioneered in the design and development of tools to effectively reduce well completion costs with TUBINGLESS completion techniques. Call, write or wire today for details on how thoroughly tested T-I-W tools can provide maximum efficiency at minimum costs.

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Tubing Testing
Single and Dual Zone Completions
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equipment is not well adapted for feeding water-insoluble organics and the tendency of present equipment to foul and become inoperative if inhibitor flushing fluid is not clean.

14-15. Rapid pumping of slugs of inhibitor into the tubing or annulus by portable "slugger pumps." The inhibitor slug is generally pumped into the well in solution or dispersion in 20-30 gallons of diluent. Contract labor can be used, but cost is high and when inhibitor is pumped into the tubing with method 15, the well must be shut-in for a relatively long period.

16-17. Spray injecton of inhibitor into a central header in a gas lift system. Inhibitor can be fed continuously by pump, or periodically by automatic applicator or timer-controlled pump. Small mechanical atomizing nozzles, which operate on 50-100 psi pressure drop, or pneumatic atomizing nozzles can be used.

This method insures excellent distribution of chemical in some difficult-to-treat systems. Mechanical atomizing injectors are adaptable into low-cost, automatic assemblies for treatment of multiple well systems.

Chief disadvantage of the method is that little or no chemical is introduced below the lowest valve. Thus, the technique sometimes needs to be supplemented by use of methods 11 or 12.

18. Addition of chemical to power oil in hydraulic pumping systems on the suction side of the surface pump. Chemical can be introduced into the downhole power oil engine to handle corrosion and deposit problems which otherwise would cause power oil engine damage. A fast-adsorbing type inhibitor is preferred.

19. Spraying of non-volatile inhibitors into the vapor spaces of sour crude storage tanks or sour well annuli. By this method, more economical non-vaporizing type inhibitors can be used in preference to non-persistent neutralizing-type, vaporizing chemicals (such as low molecular weight amines).

20. Periodic pumping of diluted inhibitor down the annulus of a sour well to coat inside of casing and outside of tubing in the annular vapor space. This method usually is carried out by use of a portable, high-output pump mounted on a truck. The pump must have sufficient capacity to flood the cross-sectional area of the annulus and insure complete contact of inhibitor with all metal surfaces in the annular vapor space.

21. Inhibiting the annulus of a sour, packed-off well by "loading" with inhibited liquid. Inhibited oil or water (usually diesel oil) is pumped into the annulus above the packer and the annulus is closed in. Typical practice involves use of a drum of oil-soluble inhibitor in 30-70 barrels of oil.

In selecting an inhibitor treating method for a given well, the operator should base his decision on a thorough study of the individual well problems as well as over-all economics and results of treating methods in use in other wells in the same field or area.

This article is based on a paper presented to the Corrosion Control Short Course at the University of Oklahoma in 1959. —**The End**

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Your industry at work

A monthly roundup of items of interest about people, companies and associations

Reviewing Material From the Oil Centennial

John F. Campbell (center), manager of Field Services, American Petroleum Institute, shows some of the material used in the oil industry's Centennial last year to Wallace Dickson (left), assistant vice president, Federal Reserve Bank of Boston, and president, New England Chapter, Public Relations Society of America. Campbell spoke to a Chapter luncheon recently on planning and execution of the Centennial program. Looking on is Hugh H. Sharpe, public affairs representative, Massachusetts Petroleum Council.

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Tello, Inc. .....TE 5-5367, UL 2-1711
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Horne Well Service Co.....3-5396
KILGORE, TEXAS
Davis-Kemp Tool Co., Inc.....5541
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LINDSAY, OKLAHOMA
Rainbo Service Co.....PL 6-2530
MIDLAND, TEXAS
Lucceus Service & Eqpt. Co.....MU 2-1631
OKLAHOMA CITY, OKLAHOMA
Rainbo Service Co.....ME 4-2131, ME 4-0105
VIDALIA, LOUISIANA
Davis-Kemp Tool Co., Inc.....435
WHITTIER, CALIFORNIA
Kline Wire Line Co.....OX 3-2731
WICHITA FALLS, TEXAS
Hudson-Eads, Inc. 322-8584
WILLISTON, N. DAKOTA
C. A. White .....GR 3-6555

Esso Standard Proposes Purchase of International

Esso Standard (Inter-America) Inc., a wholly owned affiliate of Standard Oil Company (New Jersey), has announced the terms of its offer to buy the outstanding capital stock of International Petroleum Company, Ltd.

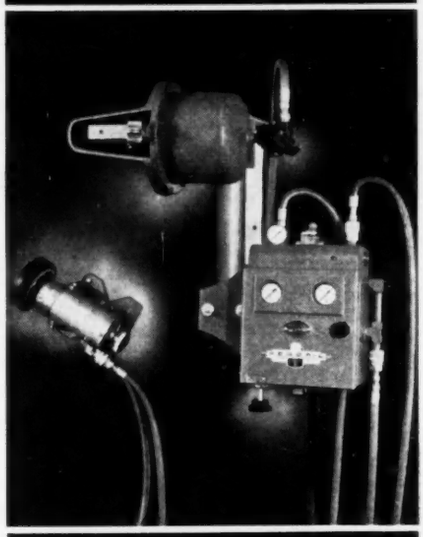
The offering price is $45, adjusted for any dividend International may declare while the offer is outstanding. The Royal Bank of Canada has agreed to receive shares pursuant to the offer. The bank will also make payment, on behalf of Esso Standard (Inter-America), as soon as transfer has been made by the Stock Transfer Agent for International.

According to a letter mailed recently to shareholders of International Petroleum, Esso Standard expects that the offer will remain open for not less than four months. The letter explains certain provisions of the Canadian Companies Act under which Esso intends to obtain all of the shares of International now outstanding. Jersey Standard, owner of more than 96 percent of International's stock, has indicated its intention to accept the offer.

Sohio Petroleum to Close Northwest Division Office

Sohio Petroleum Company will close its Northwest Division office in Billings, Mont., as a part of its program to in-

The NEW GEODRIL® AUTOMATIC DRILLER



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Service for the GEODRIL Control is provided by the experienced personnel of Geograph Oil Field Services. Their reputation for service is backed by over a fifth-of-a-century of experience in the oil fields.

When you drill your next well, specify the NEW GEODRIL Automatic Driller for maximum drilling efficiency. For additional information, contact your nearby Geograph Oil Field Services office.

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Experienced oilmen everywhere depend on R/M Vee-Square Packings for greater reliability in mud pump operation because they combine the advantages of non-yielding solid packing with the automatic sealing of V-ring design. Following are some of the ways in which R/M Vee-Square Packings can better your operations:

- **No sensitive gland adjustments . . . glands can be pulled up tight, as they should be**
- **Prevent blow-by between packing and stuffing box wall by means of a soft rubber cushion**
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- **Automatic sealing through V-ring design**

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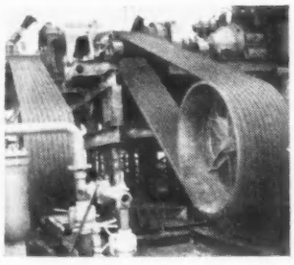

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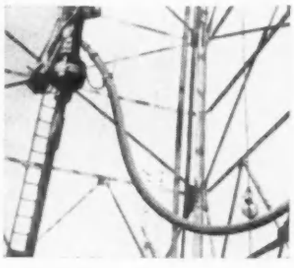

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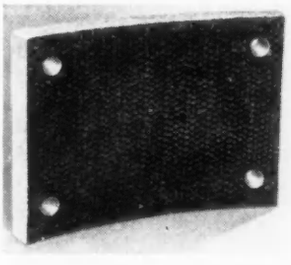
Strong • Safe • Flexible

Special high-tensile steel cable wire reinforcement, precision wound under tension, gives Ray-Man CBL Rotary Hose unequalled strength and flexibility for safer, easier handling and make-up on the rig. Resists kinking and accidental crushing in transport . . . holds steadier in the derrick *without whipping*—even under high pressures of deep drilling. Streamlined, built-in coupling has no protruding lugs or flanges—features R/M leak-proof "Lip-Lok" seal that tightens under pressure to prevent blowouts! Write for Oilfield Hose Bulletin M651.



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CONDOR LS V-BELTS

Length Stabilized

No whip, no wobble, no weave—no undue stress or V-belt turnover on long center, heavy duty oilfield drives! Condor LS V-Belts are *length stabilized* to give a degree of lateral and longitudinal stability *without stretch* never before possible. They're length *certified*, too . . . measured, tagged and vacuum packaged to assure positive length control and freshness from factory to field to drive. Condor LS V-Belts come matched—stay matched to outperform, outlast any other V-belt under the heaviest loads. Write for Bulletin M210.

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crease effectiveness of its oil and gas exploration efforts. Oklahoma City will continue as headquarters for the company's production organization under Frank R. Willibrand, general manager.

Howard B. Shelton, who has been division manager in Billings, will head the gas-gasoline division at Oklahoma City, reporting to Willibrand. The company's exploration organization, with R. W. Edmunds as general manager, will also continue headquarters in Oklahoma City. Many of the approximately 45 employes at the Billings office will be transferred to other areas.

Anchor Marks Milestone

Three owners of Anchor Petroleum Company of Tulsa celebrate the occasion of the firm's twentieth birthday. W. A. Baden, Anchor president (left), points to the ice sculpture symbolizing the event as B. B. Blair (center), vice president, and L. F. Rooney, secretary-treasurer, look on.

Union Oil & Gas Plans Merger With Texas Natural Gasoline

Richard T. Lyons, president of Union Oil & Gas Corporation of Louisiana of Houston, and John T. Oxley, president of Texas Natural Gasoline Corporation of Tulsa, have announced that the directors of their respective companies had entered into an agreement of merger whereby Texas Natural and Union will be merged. The merged company will be known as Union Texas Natural Gas Corporation.

Under the terms of the agreement, each stockholder of Texas will receive 1⅛ shares of the combined A and B common stock of the new company for each share of Texas Natural. The stockholders of Union will retain their present stock. After the merger is effected, the company will have outstanding a total of 7,043,741 shares of its capital stock.

Oxley will become executive vice president, a director and a member of the executive committee of Union-Texas. Lyons will continue as president and chief executive officer of the company. The board of directors of the new company will include Frank M. Engle and Roger S. Randolph, both of Tulsa; William A. M. Burden of New York will become chairman of the board and Mark J. Mallard of New York will become chairman of the executive committee.

Jade Oil Company Buys Admiral Drilling Company

Jade Oil Company of Beverly Hills, Calif., has purchased all producing properties of Admiral Drilling Company of Houston. The amount of cash involved in the transaction was not disclosed.

The purchase included 13 wells in the Gulf Coast and North Texas areas. Eight of the wells are gas producers and five are oil. Approximately 3,000 acres were involved in the purchase and this included additional proven acreage.

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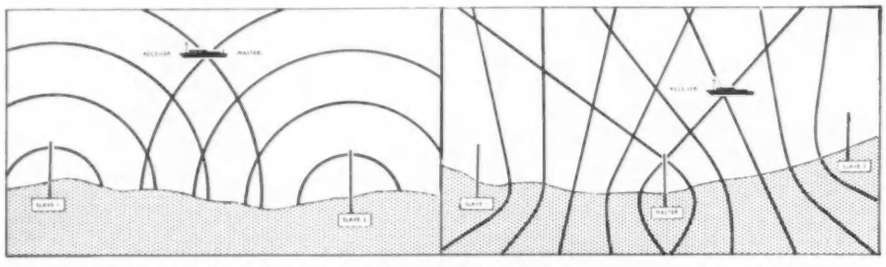

HI-FIX equipment can be deployed in either the TWO RANGE or HYPERBOLIC forms by deploying the master station ashore or on the survey vessel, no equipment changes being required

TWO RANGE HI-FIX
The two-range version gives the maximum accuracy obtainable from the system with only two shore stations and no lattice charts.

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The hyperbolic layout provides a high accuracy service for an unlimited number of users simultaneously.

HI-FIX is the answer for those small inshore areas where hyperbolic or Two Range Decca is not justified on economic grounds. Normal Decca and HI-FIX stations can be co-sited to give the precision pattern inshore (lane identified by the normal patterns) combined with the long working range of the normal Decca System.

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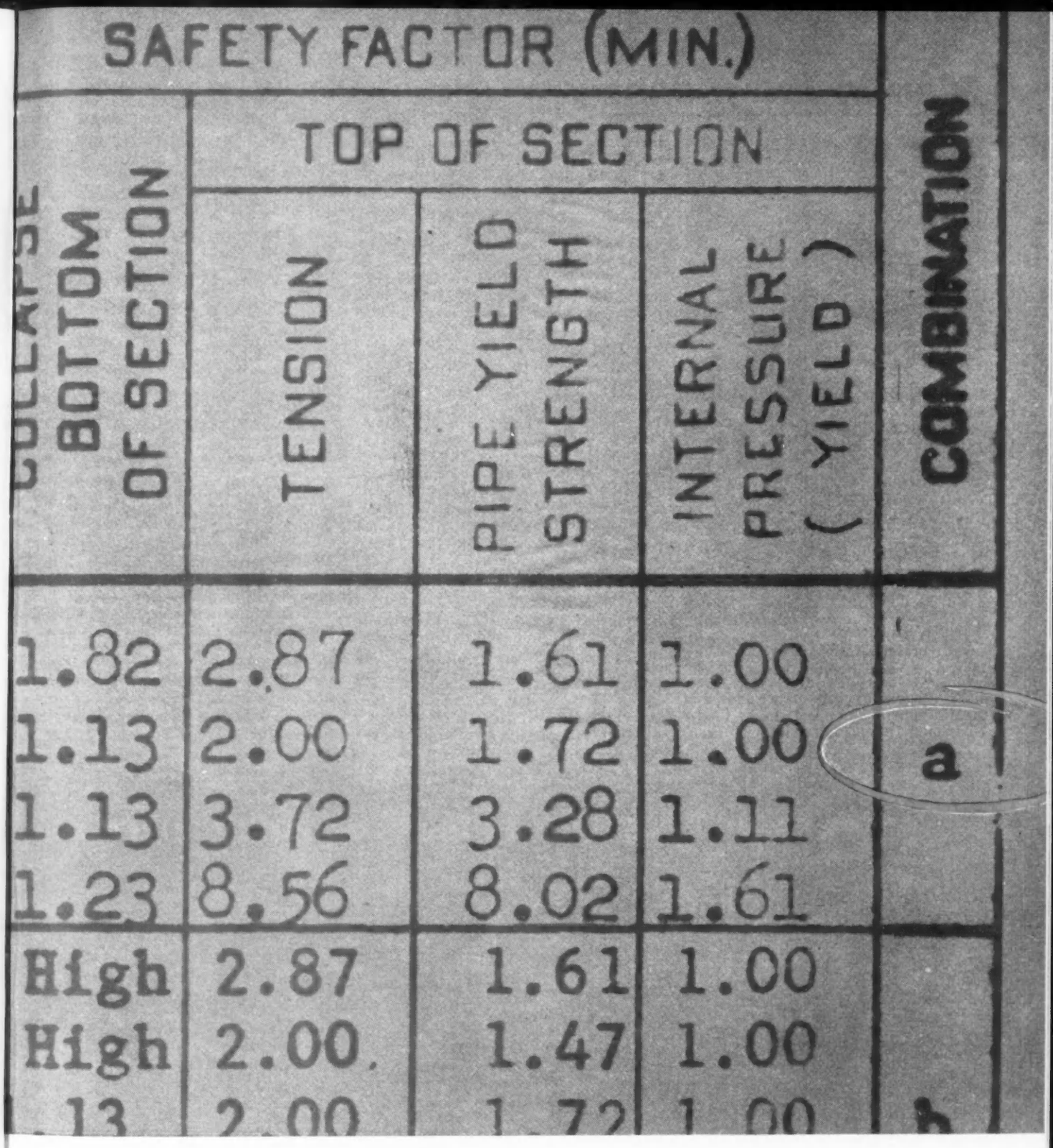

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	TOP OF SECTION			
COLLAPSE BOTTOM OF SECTION	TENSION	PIPE YIELD STRENGTH	INTERNAL PRESSURE (YIELD)	COMBINATION
1.82	2.87	1.61	1.00	
1.13	2.00	1.72	1.00	a
1.13	3.72	3.28	1.11	
1.23	8.56	8.02	1.61	
High	2.87	1.61	1.00	
High	2.00	1.47	1.00	
.13	2.00	1.72	1.00	b

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Men in the industry

R. B. Alcott

R. C. Davidson

Roy B. Alcott has been named employe relations manager of **Tidewater Oil Company's** 14-state eastern division with headquarters in New York City. **Robert C. Davidson** has been appointed western division public relations manager, and **Irving E. Chapman** has been named assistant general manager of Tidewater's 14-state eastern division.

I. E. Chapman

J. H. Adams, formerly area engineer in the Shreveport, La., office of **The Carter Division of Humble Oil & Refining Company,** has been transferred to Billings, Mont., where he will assume the duties of area engineer of the company's northern area operations. Adams replaces **L. M. Lyon** who has accepted a position with the Producing Co-ordination Department of the **Standard Oil Company (New Jersey). R. M. Pitcher** remains in Shreveport replacing Adams as area engineer for the company's southern area operations.

Dr. John C. Reed is scheduled to join the **Arctic Institute of North America** in Montreal as executive director in May. Dr. Reed is a senior geologist in the office of the director, **United States Geological Survey** in Washington, D. C.

Hugh S. Kelly has been appointed manager of the Product Planning Department for **Mobil Oil Company,** operating division of **Socony Mobil Oil Co.** in the United States and Canada.

Murray B. Quigles, Jr., Union Producing Company employe since 1946 and a member of the firm's Houston staff since 1956, has been promoted to district drilling and production superintendent. He succeeds the retired **Quincy L. Henson.**

Bruce W. Gambill, industrial relations assistant for **Sinclair Oil & Gas Company, Tulsa,** has been appointed acting manager of industrial relations, replacing **C. D. Owens, Jr.,** who transferred to New York City.

Porter Wharton, Jr., has joined **Kerr-McGee Oil Industries, Inc.,** as director of Public Relations.

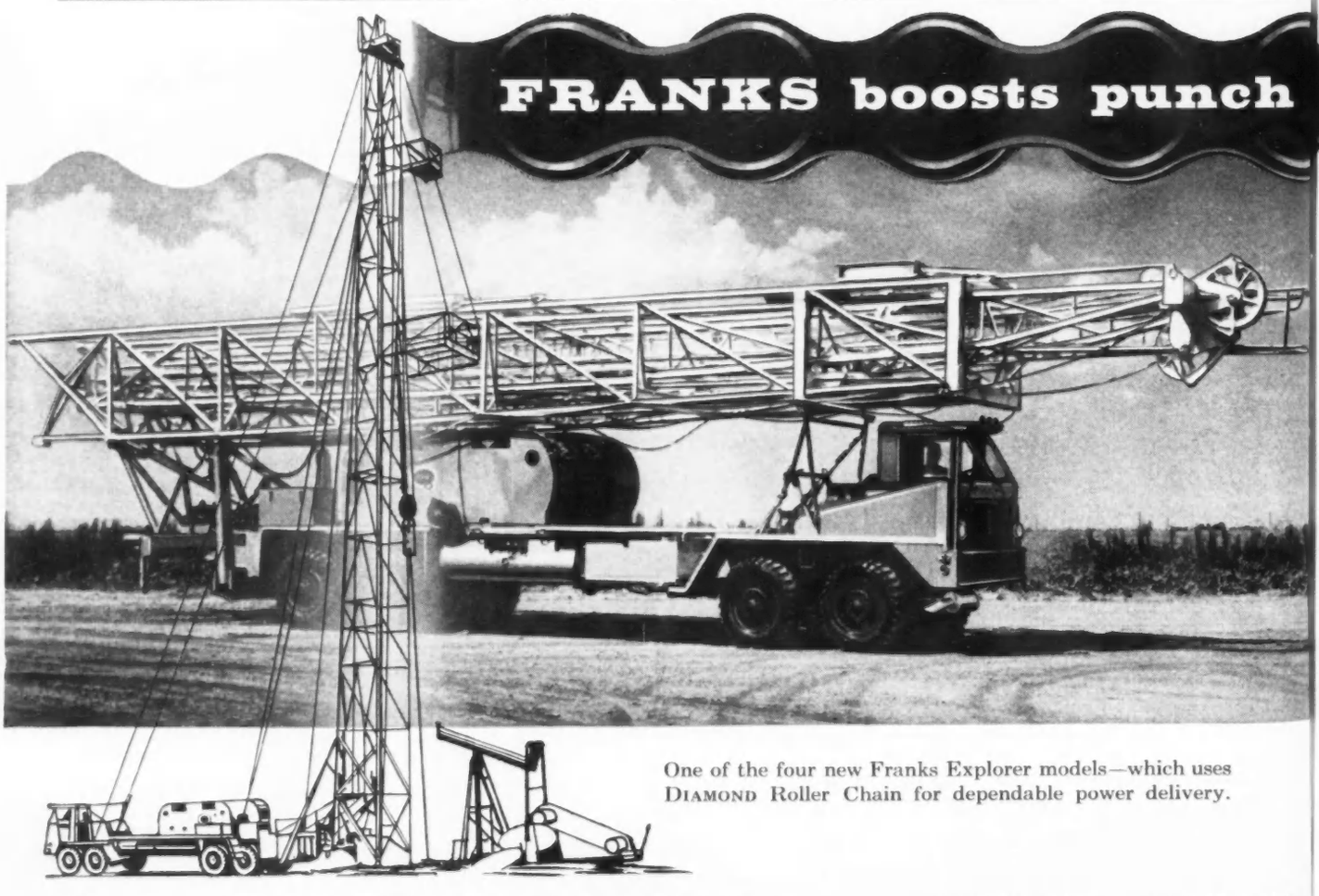
S. H. Lloyd

Sam H. Lloyd has been elected a vice president of the **Blue Water Drilling Corporation.** Lloyd has served as manager of offshore drilling operations in the Gulf of Mexico and will continue to manage these operations.

James Fitchette has been appointed manager of the public relations division of the Advertising and Public Relations Department for Phillips Petroleum Company.

Donald I. Andrews has resigned as district geologist for the Continental Oil Company and has become associated with the firm of **Rodgers, Seglund and Shaw Associates, Oil & Gas Consultants.**

K. H. Shaffer has moved from president to chairman of **Standard Oil Company** of Houston. **J. E. Gosline,** now vice president of **California Company,** is the new president.



One of the four new Franks Explorer models—which uses DIAMOND Roller Chain for dependable power delivery.

Hugh M. Keeley has been appointed regional assistant for **Mobil International Oil Company's** West Africa operations.

Dr. Hugh H. Horowitz, Erwin H. Manny and **William C. Howell, Jr.,** have been named to associate posts by **Esso Research and Engineering Company.** All three men are in the company's Products Research Division.

A. M. McLachlin

B. V. Barker

A. M. McLachlin has been appointed production manager of **Shell Oil Company of Canada's** Regina Division. He succeeds **B. V. Barker** who has been transferred to Calgary as special assistant to the production manager.

John H. Wiese has been transferred from exploration to production research by **Richfield Oil Company.**

David M. Thorton, general counsel and land manager of **Murphy Oil Company** of Oklahoma, has resigned to enter the general practice of law and will specialize in oil and gas matters.

J. A. Horner, formerly secretary of **Shell Oil Company** in New York, has assumed the presidency of **Shell Pipe Line Corporation.**

Joseph H. Morero, vice president of the Geological Department of **Skelly Oil Company,** has been elected a director of the company. Morero succeeds **W. K. Bullock.**

Jack Raglin, Houston, has been appointed to the newly created position of assistant director of public affairs for **Continental Oil Company.** Raglin was formerly administrative assistant to the president of Continental.

Selwyn Eddy, vice president of **Shell Oil Company,** has been elected chairman of the **West Coast District Oil Information Committee for 1960-61.** He succeeds **W. G. King, Jr., Richfield Oil Corporation** vice president.

John S. Sprowls, a vice president and assistant to the president of **The Vickers Petroleum Company, Inc.,** has been elected to the company's board of directors.

G. Curtis Mayes has been named joint interests manager for **Mobil International Oil Company.** He will advise on producing questions relating to the firm's joint interests in the Middle East.

Peter C. Petroutson has been elected assistant vice president of the **Merchants National Bank of Mobile.** He has been in the bank's Oil Department since May 1957. Before entering the employment of the Merchants National, Petroutson was employed by the Pan American Petroleum Corporation. He has a degree in petroleum engineering from the Colorado School of Mines.

P. C. Petroutson

Frank Perkins, Jr., formerly district manager for Schlumberger in Lubbock, Texas, has resigned to do independent petroleum consulting work. Perkins will be located in Lake Charles, La.

Francis X. Owens has been named training supervisor of **Tidewater Oil Company's** eastern division.

W. A. (Bill) Hover has joined **Zapata Petroleum Corporation** of Midland, Texas, as vice president. He will make his headquarters in Midland at the firm's general offices.

L. C. Stevens has been named division vice president for exploration and producing of the Los Angeles division, **Mobil Oil Company.** Stevens will assume his new position on completion about March 31.

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DIAMOND Roller Chains deliver power with a punch—up to 400 horses—from this new, powerful, self-propelled servicing and workover rig. *Dependable* power is important. That's why more and more equipment manufacturers rely on DIAMOND Roller Chain for greater strength, longer wear and highest efficiency under the most rugged oil field conditions. Specify DIAMOND for economy too—your oil field store carries complete stocks.

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For name of your DIAMOND chain supplier, see the Yellow Pages of your phone book under the heading of CHAINS-ROLLER.

Men in the industry

Arthur L. Lanckton has been appointed an executive vice president of **Mobil International Oil Company.** Lanckton will be in charge of the company's staff services which has been grouped together.

G. M. (Mike) Pennock and **J. W. (Jim) Herod** have been named vice presidents with the **Anchor Petroleum Company.**

C. Hayden Atchison, formerly division manager of exploration for **The British-American Oil Producing Company's** Southwestern Division in Midland, Texas, has been promoted to the position of exploration coordinator at the company's offices in Dallas.

P. L. Henderson

G. F. Bish

Paul L. Henderson has become vice president of international production and **Glenn F. Bish** has become vice president of domestic production for **The Ohio Oil Company.**

Robert D. Anson, exploration manager for **Bell Oil & Gas Company,** has resigned his position. No future plans have been made known.

Howard Brooks, formerly chief scout of the **Magnolia Petroleum Company** before its merger with **Socony Mobil Oil Co.,** has been transferred to Tallahassee, Fla., as division scout for the **Mobil Oil Co.**

J. A. Dykes, attorney at Shreveport, La., has joined the oil firm of **Lyons and Lyons.**

Joe Mefford, assistant division production superintendent with the Tulsa division of **Sinclair Oil & Gas Company,** has been promoted to division production superintendent with the Midland, Texas, division. He succeeds **O. G. Simpson** who was named assistant division manager at Midland.

Dwain L. Williams has been appointed district representative of the domestic crude oil supply for **Gulf Oil Corporation.** He will continue to headquarter in Denver where he was formerly a scout.

Orville W. Farlow, Jr., senior petroleum engineer with **Sinclair Oil & Gas Company's** Fort Morgan, Colo., production district, has been transferred to the Houston division.

G. A. Peterkin

George A. Peterkin, chairman of the board of the Houston Contracting Company, has been elected to the board of directors of **Falcon Seaboard Drilling Company** of Tulsa.

Francis C. Savage has been named manager of **Mobil International's** Distribution Planning Department.

John A. Bruss has been appointed assistant treasurer of **Clark Oil and Refining Corporation.**

Clark A. Gruver has been appointed assistant manager of **Mobil Oil of Canada, Ltd., (Libyan Branch)** an affiliate of **Mobil International Oil Company.** The company headquarters is in Tripoli, Libya.

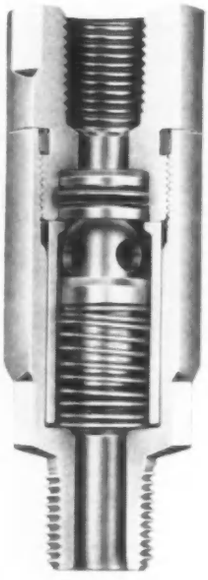
T. C. Bartling, executive vice president of **Apache Oil Corporation,** has been appointed to the imported oil policy committee of the **Independent Petroleum Association of America.** Bartling heads Apache's Exploration Department, with headquarters in Tulsa.

William M. Cocke has been elected vice president and general manager of **Cit-On Oil Corporation,** a dual subsidiary of **Cities Service Company** and **Continental Oil Company.**

H B

Gas Lift Check Valves Prevent Damaging Backwash

• Protect the heart of gas lift valves with Harold Brown normally seated check valves. Available in three types—"AM" Magnetic Check Valve—"B" Gravity Check Valve—"S" Spring loaded Check Valve.



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Positive Ball Seal
Non-weakening magnetic action
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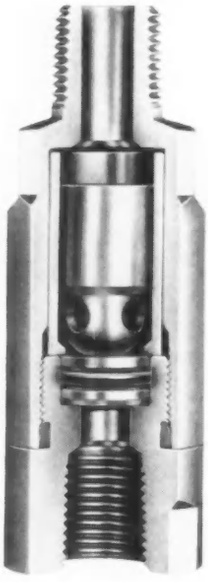
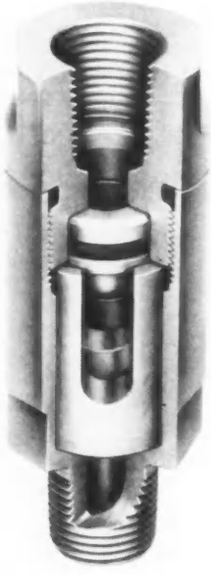
Made from Monel and high nickel alloys



Type "S" Spring Loaded Check Valve
Spring protected from flow stream
Heat treated K-Monel insert seat
Long life Monel spring



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Non-fouling Drop
Heat treated insert seat and drop

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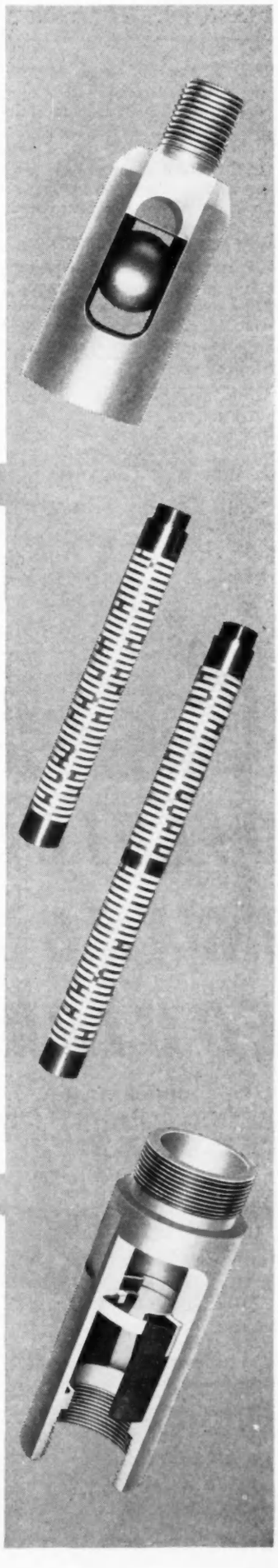

Both **MARTIN PLUNGERS** and **MARTIN RUBBER GUIDE CAGES** are the result of correct engineering to fully utilize the excellent properties of rubber.

In the **MARTIN SPLIT RINGS,** even the swelling of natural rubber in oil is utilized in sealing the split and tightening the rings in the PLUNGER GROOVES. **Resistance to abrasion** greatly prolongs plunger life in sandy conditions. **Slippery when wet** means that you have lubrication, even when pumping all water. Barrel life is increased because this material cannot score or gall metal.

For the **REPLACEABLE RUBBER GUIDES** in cages, **oil resistant** synthetic rubber is used. No swelling can be tolerated here. **Resilience** completely eliminates the beating action of the ball, and greatly increases ball life. **Resistance to abrasion** reduces wear on both guide and ball.

CUT YOUR COSTS . . . LET RUBBER TAKE THE WEAR . . . Write for our new 1960 catalog.

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Manufacturer

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Men in the industry

John F. Curran, senior attorney at **Sunray Mid-Continent Oil Company,** has been named assistant general attorney for the company.

Dr. Edward P. Luongo has been appointed regional medical director for the West Coast of **Mobil Oil Company.**

A. F. Woodward has been appointed manager of field and exploration operations, Pacific Coast Division, for **Union Oil Company of California.** At the same time, **C. F. Bowden** was appointed assistant to the vice president in charge of production.

Quilman B. Davis

A. L. Ward

Quilman B. Davis, formerly secretary and general attorney for **Aztec Oil & Gas Company,** was promoted to vice president and general attorney. **Arland L. Ward,** treasurer, was promoted to secretary and treasurer. **A. E. Oldham,** independent geologist of Dallas, was elected a member of the board of directors.

W. F. Eiting, Jr., assistant production manager for **Humble Oil & Refining Company, Carter Division,** has been named eastern area manager for the company with headquarters at Mattoon, Ill. He succeeds **R. P. Ryan** who was recently appointed general counsel and a member of the board of management of Humble's Carter Division. **R. E. Hammond,** production manager for Humble's eastern area operations at Mattoon, will replace Eiting in Tulsa as assistant production manager.

Dr. R. W. Brauchli, Oklahoma City, has been made vice president of Exploration and Production for **Anderson-Pritchard Oil Corporation.** APCO has consolidated its production and exploration activities into a single department. The division heads will report to the vice president.

R. E. Griswold has been appointed assistant to the Dallas Division manager in the Domestic Producing Department of **Texaco Inc.**

Robert H. Park was promoted to assistant division manager, Gas Division of the Domestic Producing Department of **Texaco Inc.** Also, **Erwin A. Gromatsky** was advanced to chief gas engineer, general manager's office, Domestic Producing Department. Both Park and Gromatsky will be located in Houston.

C. Norman Ramsey, of Birmingham, Ala., has been elected a vice president of **Republic National Bank of Dallas.**

Jack W. Roach was recently named vice president-personnel of **Kerr-McGee Oil Industries, Inc.** Also, five members of Kerr-McGee's Production and Drilling Operations Division were appointed to new posts. They include: **Charles F. Miller,** manager of foreign production and drilling operations; Kenneth W. Parker, project superintendent, Bolivian operations; **Burrell G. Taylor,** manager of Production Department; **Harry C. Hanna,** general superintendent of Production Department, and **John I. Fisher,** who continues as superintendent of gas contracts, was given the additional responsibility of supervising the Production Department engineering section.

John P. Carnes, district landman at Shreveport, La., for **Sun Oil Company,** transferred as district landman to Roswell, N. M. Senior Landman **Paxton Robertson** of Lubbock, Texas, was moved to Shreveport succeeding Carnes. **W. O. (Bill) DeWitt,** scout at Midland, Texas, was named junior landman to fill the vacancy created by Robertson. DeWitt will continue to have his office in Midland. Roswell Scout **Frank Haughton** was promoted to junior landman and will move to Abilene, Texas. **George McFall,** draftsman in the Dallas office, transferred to Roswell as junior scout. **Jack Everett,** formerly in Sun Oil's Title Record Department, Dallas, has moved to Midland as a junior scout.

OILFIELD TRUCK AND FLOAT

Thornycroft Sandmaster 252" wheel base Oilfield Truck. Hands-England full Oilfield Body. 60,000 lb. winch, heavy duty gin poles, winch operated gin pole risers and folding SAE king pin.
Hands-England 75,000 lb. capacity, tandem axle Oilfield Float 30' 0" long and 9' 6" wide, folding support legs and inverted 36" fifth wheel.
Truck and Float on Michelin 18.00 x 25. Sahara "X" sand tires.

OILFIELD TRANSPORTATION EQUIPMENT

OILFIELD FLOAT

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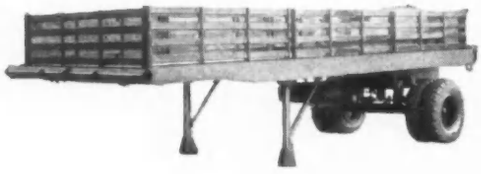
Float on 11.00 x 20 — 14-ply tires.

OILFIELD TRUCK AND FLOAT

Scammel Constructor 261" wheel base Oilfield Truck.
Hands-England 75,000 lb. capacity tandem axle Oilfield Float 30' 0" long and 9' 6" wide, folding support legs and inverted 36" fifth wheel.
Truck and Float on 14.00 x 20—18-ply tires.

OILFIELD FLOAT

Hands-England 25,000 lb. capacity single axle Oilfield Float 24' 0" long and 8' 0" wide, folding support legs and SAE king pin 11.00 x 20—12-ply tires. Steel stake sides.



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Double Gray-X will be made in a wide range of sizes and constructions to give greater operating economy and reduced downtime for all types of rope-using equipment. It will be available soon from CF&I-Wickwire's chain of warehouses and through a network of nationwide distributors.

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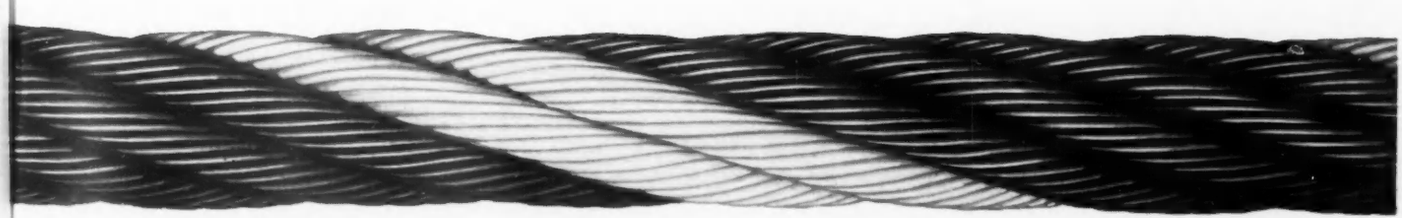

Men in the industry

V. C. Scott was promoted to chief geologist of the Domestic Producing Department of **Texaco Inc.**

John R. Puryear has been advanced to the position of regional geologist for **Plymouth Oil Company.** Puryear succeeds **A. Lee Jones** who has retired.

Dudley P. Penick was appointed staff gas engineer for **Mobil International Oil Company** in New York. He will have staff responsibility for gas production, separation, processing and utilization in all Mobil International operations.

Edwin C. McDonald and **Colin W. Webster** were named to the board of **Pacific Petroleums Ltd.**

Fred L. Hartley, vice president of **Union Oil Company of California** was elected a director and senior vice president at a regular meeting of the company board of directors. He will assume executive responsibility for all marketing operations.

L. M. Spleth, formerly division landman in Denver, has been named assistant regional manager and regional landman of the southwest region, headquartered in Bartlesville, Okla., for Phillips Petroleum Company. He succeeds **J. H. Sneed** who transferred to the International Department. **C. E. Campbell,** formerly assistant division landman in Amarillo, Texas, was named regional landman, northwest region, in Bartlesville, succeeding **E. M. Gorence** who transferred to the department's Midland, Texas, division office.

W. A. Walther, Jr.

William A. Walther, Jr., assistant division production superintendent for **Sinclair Oil & Gas Company** at Houston, has transferred to Tulsa as assistant division production superintendent of the Tulsa Division. He succeeds **Joe Medford,** promoted to division production superintendent at Midland, Texas.

Dr. Robert Foreman, a member of the professional staff at **Sohio's Research Center,** Cleveland, Ohio, was promoted to the position of senior research associate in the Research Department.

Frank T. Grassy has been elected a vice president of the **Great Northern Oil Company.**

David L. Campbell, formerly vice president, has been elected executive vice president of **British American Oil,** and **Clarence D. Shepard, Q. C.,** general counsel, was elected a vice president and director.

Vernon L. Mattson, manager of mineral development and research at **Kerr-McGee Oil Industries'** research laboratories in Golden, Colo., has been promoted to manager of mining and milling at the company's home office in Oklahoma City.

Lloyd R. Austin, formerly an executive for Standard Oil Company (Indiana) in Milwaukee, Wis., has been named assistant general manager, operations and administration, in the Marketing Department of the **American Oil Company** in New York. He will report to **C. H. Couglin.**

Lewis P. Blanton has been appointed chairman of the **Federal Petroleum Board.** He succeeds **Nelson Puett** who has been on temporary status as chairman, preliminary to retirement.

Darwin W. Ferguson recently was elected president and director of **Sun Oil Company, Ltd.** Ferguson replaces **Wilburn T. Askew** who was the first resident president of the company.

F. Ward O'Malley, formerly with the Tidewater Oil Company in Turkey, has joined **Iran Pan American Oil Company** as exploration manager.

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Shot hole drillers the world over find Hawthorne "Blue Demon" Insert Rock Bits sure-shot cost cutters for their exploration drilling.

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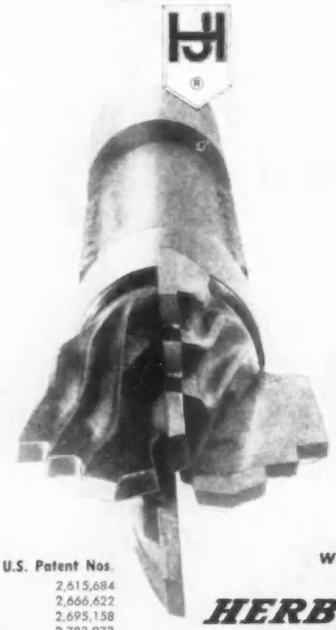

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Associations

These Dallas-Fort Worth NOMADS Chapter 1960 officers were installed recently. They are (left to right, top row) R. E. Elmore, Rollo Davidson and Courtney J. Berlin, regents. (Middle row) J. A. Kelly, vice president, Dallas; Eric Sutton, deputy sergeant-at-arms, and Ramon H. Robinson, sergeant-at-arms. (Bottom row) Charles Edd Trapp, vice president-regional; Robert H. McLemore, executive vice president; Harry S. Zane, Jr., president; William C. Brooks, vice president, Fort Worth, and K. Marshall Fagin, treasurer. (Not pictured) G. A. Holloway, secretary; T. Gayle Whiddon, assistant secretary, and Webb M. Sowden, assistant treasurer.

Tulsa Chapter NOMADS officers for 1960 are (left to right, front row) Oscar B. Irizarry, senior regent; T. D. Williamson, Jr., deputy sergeant-at-arms; John Pearce, third year regent; Paul V. McGivern, president; Harry S. Horton, secretary; R. R. Matthews, assistant treasurer; Larry Harper, sergeant-at-arms, and T. M. Lumly, junior regent. (Left to right, back row) Floyd C. Cummings, assistant secretary; W. O. Timberlake, vice president, and E. M. Donovan, treasurer.

The 1960 officers of the Los Angeles Chapter of NOMADS at the Twenty-First Annual Inaugural Ball are shown with the Master of Ceremonies Lee Laird of Ladish Pacific Division, standing behind. New officers are (left to right) B. Bronzan, McCullough Tool Company, deputy sergeant-at-arms; Willard Goertz, Monarch Engineering Corporation, assistant treasurer; P. M. Bowen, Martin-Decker Corporation, treasurer; Lester G. Evans, Axelson Mfg. Company, secretary; Charles M. King, Baker Oil Tools, Inc., vice president; Tom R. Ashe, Globe Oil Tools Company, regent; Taylor Bannerman, Technical Oil Tool Corporation, president; Earl M. Daniels, Hydril Company, regent; Robert P. Gaylord, Wagner-Morehouse, Inc., regent; C. C. Sutton, Oil Well Mfg. Company, assistant secretary, and Jack S. Smith, Byron Jackson Tools, Inc., sergeant-at-arms.

Oklahoma Independents Elect P. Schultz To Fourth Term

Paul R. Schultz, president of Blackwell Oil & Gas Company, Tulsa, was elected to a fourth term as president of the Oklahoma Independent Petroleum Association in a directors meeting recently which wound up the association's annual convention.

Directors met after convention general sessions closed. Re-elected with Schultz were E. A. Smith, president of Service Drilling Company, Tulsa, as vice president, and John J. Robertson of Shawnee, secretary-treasurer.

Abilene Geological Society Elects Officers for 1960

Louis A. Williams, Sun Oil Company, has been elected president of the Abilene Geological Society. Other new officers are: Jack B. Ryan, Jake L. Hamon, oil producer, vice president; Frank L. Schatz, Sun Oil Company, secretary; and Eugene M. Goltz, Katz Oil Company, treasurer.

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Associations

Houston Chapter NOMADS officers for 1960 are: (Front row) E. W. Louden, James B. Hughes, B. H. Pickard, all national regents; John W. Gates, president; Bruce Barkis, vice president. (Back row) J. W. Wallace, sergeant-at-arms; Kenneth P. Morris, assistant treasurer; Bernard J. Gross, treasurer; Fred A. Christanelli, secretary; Beau A. Wendt, deputy sergeant-at-arms, and Terry W. Russell, assistant secretary.

H. V. Howe To Receive Highest Award of AAPG

Henry V. Howe, director of the School of Geology, Louisiana State University, Baton Rouge, La., has been chosen to receive the Sidney Powers Memorial Medal, highest honor in petroleum geology, from the American Association of Petroleum Geologists. The gold medal and scroll will be formally presented Tuesday, April 26, 1960, at the forty-fifth annual meeting of the association in Atlantic City, N. J. The presentation will be made by Harold N. Fisk, Humble Oil & Refining Company, Houston.

Dr. Howe is the thirteenth recipient of this award, which was established by the Association in 1943. The award is made in recognition of distinguished and outstanding contributions to or achievements in petroleum geology.

Also, the AAPG has announced that the following recipients will receive honorary memberships in the association at the annual meeting: Leonidas T. Barrow, Houston; Charles J. Hares, Boulder, Colo.; Roy T. Hazzard, Rocksprings, Texas; Samuel H. Knight, head, Department of Geology, University of Wyoming, Laramie; Robert B. Moran, consultant, Pasadena, Calif., and Edgar W. Owen, consultant, San Antonio, Texas.

Officers and Directors Named by Gulf Coast SPE

The new officers for 1960 have been announced by the Gulf Coast Section Society of Petroleum Engineers of AIME. They are: Pete W. Cawthon, Jr., First City National Bank of Houston, chairman; William M. McCardell, Humble Oil & Refining Company, vice chairman; Jack McWilliams, Pan American Petroleum Corporation, secretary-treasurer and E. A. Rassinier, Trunkline Gas Company, section delegate.

The new directors are: J. Don Clark, Union Oil Company of California; W. J. Greenwald, Humble Oil & Refining Company; M. Scott Kraemer, Pan American Petroleum Corporation, and Gene L. Scheirman, Shell Oil Company.

API Honors Four for Past Service

The American Petroleum Institute awarded four oil men the "API Citation for Service" at the API Southwestern District Meeting held recently in Dallas. L. E. Fitzjarrald, API vice president for production, and vice president of Phillips Petroleum Company, Bartlesville, Okla., made the presentations. The recipients included (left to right) Tom B. Campbell, J. P. (Bum) Gibbins, Inc., Midland, Texas; Harry N. Stansbury, The Atlantic Refining Company, Dallas; Fitzjarrald; Wayne C. Moody, Sunray Mid-Continent Oil Company, Midland, and W. R. Johnston, Aspen Drilling Company, Albuquerque, N. M. Campbell was honored for his work as district vice chairman in 1957-58. Stansbury's award is in recognition of outstanding service as chairman of the API group which compiled the special volume, "Oilwell Cementing Practices in the United States." The award to Moody acknowledges his leadership on standardization of subsurface pumps, and Johnston's citation refers to conspicuous service while chairman of the district in 1957-58.

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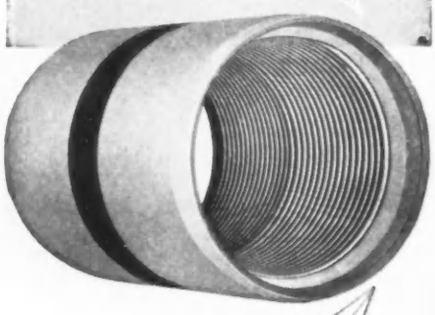

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Anvil Brand Fittings—A.P.I. couplings for all regular oil field applications, bushings, plugs, and nipples— undergo scientific materials testing and continual gaging during manufacture. They are sold through your nearest supply store, whose engineering service to customers is supported by Anvil Brand Representatives in key locations. Write today for further information.

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Suppliers' notes

Lloyd Hymel

C. C. Warren

Charles Shake

Lloyd Hymel has been appointed manager of the Harvey, La., Division for the **Tuboscope Company, Charles C. Warren** has been named manager of the Laurel, Miss., Division, and **Charles (Chuck) Shake** has been named manager of the Houma, La., Division.

F. A. W. Anger has been promoted to vice president of manufacturing and **Robert Duff Clark** was appointed director of research and development for **The Axelson Division of U.S. Industries, Inc.**

F. M. Morris has been appointed vice president and **Vesper Armstrong, Jr.,** as secretary-treasurer of the **Longhorn Supply Company.**

R. R. (Bob) Willis has been promoted from assistant to district manager for the well logging division in the Oklahoma Division, Oklahoma City, for **Hycalog, Inc.; W. H. Bradford** was made district manager of the Oklahoma-Kansas Division with headquarters at Liberal, Kan.; **F. T. Pittman** was upped to sales engineer in Maracaibo, Venezuela. **Jess Gilbert** was promoted to district manager of the Oklahoma area, Diamond Equipment Division, Oklahoma City; **E. W. Ferguson** has been promoted to district for the Diamond Division at Odessa, Texas; **Frank Kruta** has been employed as sales engineer in the Casper, Wyo., District, with offices at Billings, Mont.; **E. V. Nesbitt** has been transferred from South Louisiana to the Oklahoma District office at Oklahoma City, and **John A. Norwood** has been transferred to the South Louisiana District from Oklahoma with headquarters at New Orleans.

John V. Page has been named comptroller of **Graver Tank & Mfg. Co., Division of Union Tank Car Company.** Page succeeds **William Hopewell** who resigned.

N. L. Cain has been appointed as field representative at Williston, N. D., for **U. S. Steel's Oil Well Supply Division,** and **A. C. Johnstone** has been appointed as field representative at Swans Hill, Canada.

Edgar W. Carne, Jr., has been promoted to manager of Export Sales for the **Baash-Ross Division of Joy Manufacturing Company** and will work out of the company's Houston offices.

W. C. Norris Holds Sales Meeting

Gathered during the recent annual sales meeting of W. C. Norris, Manufacturer, Division of Dover, are members of the company's sales organization. Forty-three company representatives and officers attended the event during which new and improved products were studied. The three-day meeting was held at the Western Hills Lodge, Sequoyah State Park, Oklahoma. Seated (left to right) are William L. Butler, president, Tulsa; LeRoy Mitchell, Rocky Mountain Division manager, Casper, Wyo.; Hamp Brooke, Dallas; O. L. Scott, Canadian Division manager, Edmonton, Alta.; S. R. Hill, Calgary, Alta,; Bill Black, Casper; M. L. Parker, Odessa, Texas; H. F. Nostrand, advertising manager, Tulsa; A. L. Ethriedge, Tulsa; Bob Roberts, Corpus Christi, Texas; J. E. Giles, Oklahoma Division manager, Tulsa; J. C. Schaff, valve sales manager, Tulsa; Kenneth Hance, Salem, Ill.; Gerald Holleyman, Farmington, N.M.; G. W. Davidson, Jr., vice president of sales, Tulsa; D. P. Hagaman, general sales manager, Tulsa. Standing (left to right) J. A. Getty, Jr., chief engineer, Tulsa; C. L. Snelling, Gulf Coast Division manager, Houston; W. J. Whitaker, West Texas Division manager, Fort Worth; R. W. Clifford, Midland, Texas; M. E. McKelvey, Wichita Falls, Texas; A. A. Hardy, chief engineer, Tulsa; Dan Coates, Denver; R. L. Preston, Wichita, Kan.; W. C. Tolleson, Kilgore, Texas; J. G. Russell, Oklahoma City; D. W. Stewart, Midland, Texas; K. M. Cook, Central Division manager, Tulsa; R. L. Seale, Lafayette, La.; George White, Pampa, Texas; Don Kyle, Hobbs, N.M.; Paul Covard, Odessa; Don Smith, Hobbs; Ed Scholl, Ardmore, Okla.; Bud Burney, Odessa; Earl Carpenter, Tulsa; Don Durbin, Houston; Bill Peterson, Shreveport, La.; Joel Little, Oklahoma City; Ed Chaney, Abilene, Texas; Dwight Maney, Houston; Jim Chambers, Willston, N.D., and Gordon Shay, Houston.

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Use it because it embodies features never before combined in a needle throttling valve...

It is the first throttling and shut off valve that serves the whole range of pressures—from low to 10,000 psi—with equal efficiency all the way through.

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Bodies of the 1900 series identified by the yellow handle are machined from high grade carbon steel bar stock marked in accordance with M.S.S. regulations showing size, material and service. Stems are 416 stainless steel. Valves are available in the patterns shown below; sizes ⅛", ¼", ⅜", ½", ¾" and 1".

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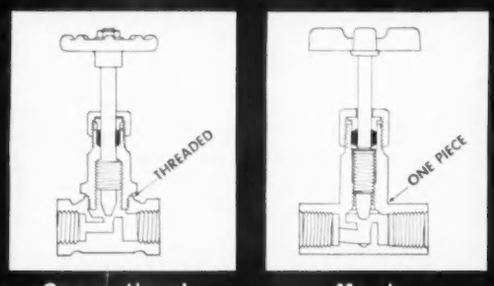

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In conventional valve (left) stem-guide is threaded into body...can be backed out when valve is fully opened, causing real trouble when pressure is high. Can't happen with Marsh design (right). Marsh stem-guide is welded to body.

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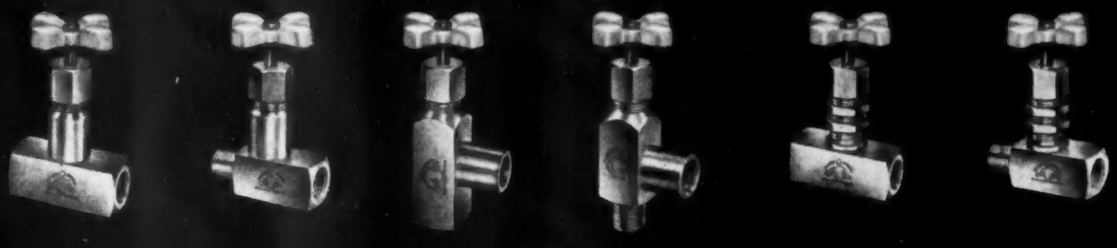
SERIES 1900

Needle Valves



Suppliers' notes

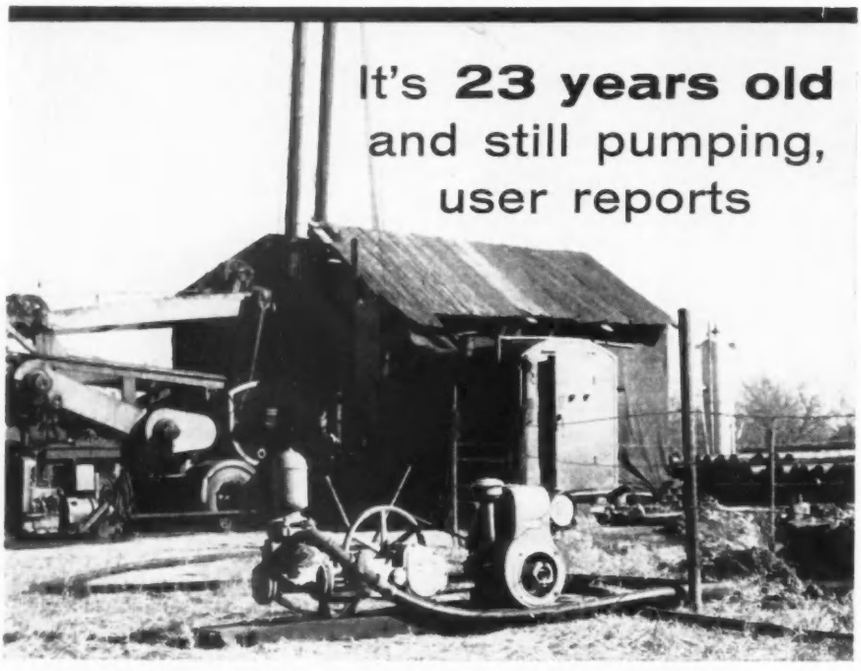
V. R. Prehn

G. W. Bone

V. R. Prehn, formerly deputy managing director of **Ruston and Hornsby Ltd.,** and **G. W. Bone,** managing director of Ruston's associate company **Davey, Paxman & Co. Ltd.,** have jointly become managing directors of Ruston and Hornsby, Ltd., following the retirement from the managing directorship of **Harold Riggall** who will remain on the board in a non-executive capacity as deputy chairman. Prehn also has become deputy chairman of the Davey, Paxman board of directors.

Robert D. Crane has been appointed director of Purchases and Traffic for **Dresser Industries, Inc.,** replacing the retired **Robert C. Kelley.**

B. J. Jostrand has been appointed vice president of **Larkin Packer Company, Division of Koehring Company.**



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Here's working proof that Wisconsin air-cooled Engines give the most hp-hours of on-the-job service.

What's more, as compared to water-cooled engines, you get the same rugged power *but with up to 26 fewer parts and ⅓ less weight.* And you never have to condition an air-cooled Wisconsin for summer or winter use. You just start it and let it run — whether it's 20° below or 140° F. above zero.

Take a tip from Mr. Edgerton — specify Wisconsin Engines for your utility units. Sizes 3 to 56 hp., with electric starting and choice of fuel system. And remember, we specialize in engine power applications for oil field use.

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Oil Field Distributors for Wisconsin Engines and all types of Utility Units

World's Largest Builders of Heavy-Duty Air-Cooled Engines

Art Morton, who has had extensive experience in oil field engineering, has been named manager of Quality Control by **Tex-Tube, Inc.**

L. E. Blackwell has been appointed a product sales engineer for the Instrumentation Product Group of the **Texas Instrument Incorporated** Geosciences & Instrumentation Division.

Kenneth P. Goepfert has been named managing director of **Twin Disc Clutch Belgium S.A.** of Brussels, Belgium. Goepfert will also serve as assistant vice president of manufacturing of **Twin Disc Clutch A.G.,** Zurich, Switzerland. Both companies are subsidiaries of **Twin Disc Clutch Company** of Racine, Wis.

K. P. Goepfert

James M. Leitch has been appointed manager of European operations at the London office for **Continental-Emsco Company (G. B.), Ltd.** a subsidiary of **Continental-Emsco Company,** a division of **The Youngstown Sheet and Tube Company.**

Wallace L. Reed has been appointed manager of the **Harley Sales Company's** Houston branch office and warehouse.

Robert Scruggs has been named by **Gardner-Denver Company** to head the new office recently opened in San Diego, Calif.

Paul Lamb has been appointed sales engineer for **Merla Tool Corporation.** Lamb, a mechanical engineer, has been a staff engineer with Merla for five years.

R. L. Frederick has been appointed to the new position of executive director-International Division of **The Timken Roller Bearing Company.** Frederick will report to **H. E. Markley,** executive vice president.

John P. DeHetre has been named to succeed **John M. Tuthill,** who has retired as general manager of sales of **The Youngstown Sheet and Tube Company.**

W. F. Krause, Jr.

William F. Krause, Jr., has been transferred to the Harvey, La., office of the **Baash-Ross Division** of **Joy Manufacturing Company.** Krause will serve as Gulf Coast area sales engineer in Harvey. Previously he had been Mid-Continent area sales engineer in Oklahoma City.

William H. Harris has been appointed field representative of **U. S. Steel's Oil Well Supply Division** at Morgan City, La.

Suppliers' notes

John Joss, formerly with Advertising and Publications Department of **Southwestern Industrial Electronics Company, a Division of Dresser Industries, Inc.,** has been appointed administrative assistant to **Leigh Taylor,** SIE's vice president of marketing.

G. E. Nevill has been appointed engineer of standards in the Product Engineering Department of the Pressure Control Equipment Division of **Cameron Iron Works, Inc.** This function will include active representation of the company on technical committees, including the API, the Association of Wellhead Equipment Manufacturers and the Manufacturers Standardization Society of the Valve and Fittings Industry.

G. E. Nevill

James A. Groves has joined **Mission Manufacturing Company** as sales representative for the Edmonton, Alta. area.

W. W. Wilson, formerly district manager at Houma, La., for **Lane-Wells Company,** a division of **Dresser Industries, Inc.,** has been transferred to Healdton, Okla., in the same capacity. **Carl Combs** has been moved from Healdton to Natchez, Miss., as district manager. **Ed Barker,** formerly at Natchez, has become the company's district manager at Houma. **Billy Bolling** has been appointed sales engineer at Lafayette, La. **E. G. Hornaday** is the new field service operating engineer in charge of the company's Liberty, Texas, operations. **D. H. (Pete) Wells** has assumed the same duties at Corpus Christi, Texas.

James F. Jenkins has been appointed store manager of **U. S. Steel's Oil Well Supply Division** at Calgary, Alta. Also, **C. B. Fisher** has been appointed store manager for the firm's Swan Hills, Canada, location. **William M. Wallace** and **William A. Slocombe** have been appointed field representative and city representative, respectively, for U. S. Steel's Oil Well Supply Division in Calgary.

M. L. Talbert

M. L. Talbert has been named vice president-engineering of **Security Engineering Division,** one of the **Dresser Industries.** Formerly chief engineer for Security, Talbert has responsibility for all engineering activities. He has been active in various capacities in the engineering of drilling bits for nearly 23 years.

Hughes Tool and Mexican Firm Reach Manufacturing Agreement

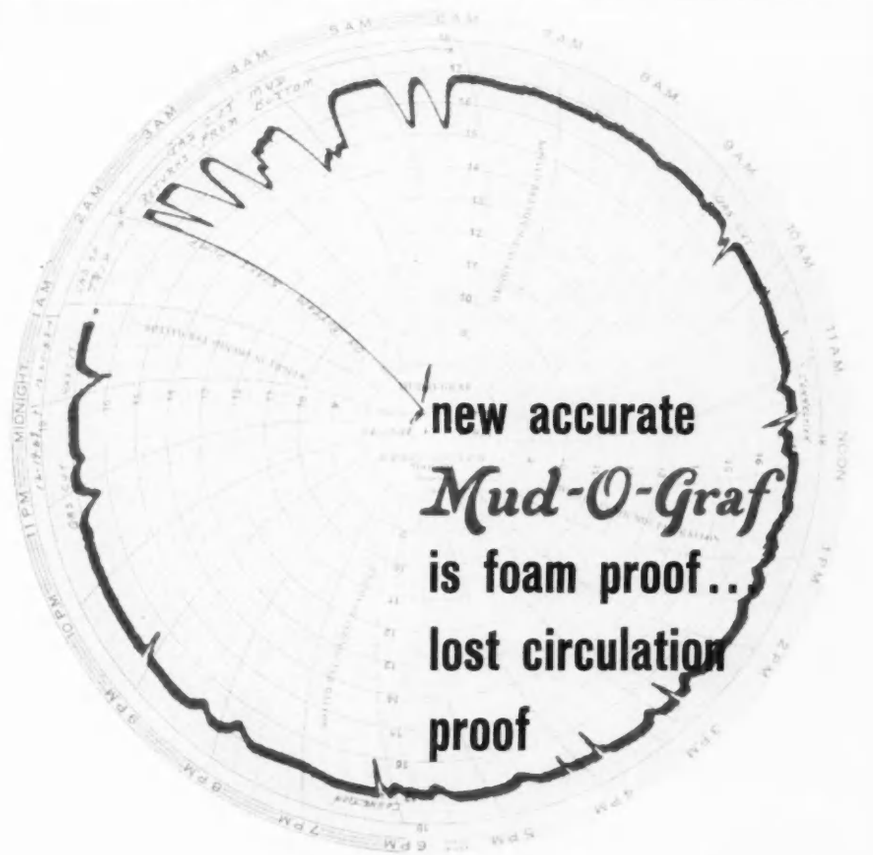
Hughes Tool Company of Houston and Herramientas de Acero, S. A. de C. V., of Mexico City, have announced a manufacturing agreement under which rotary rock bits and tool joints will be made in Mexico for use by the Mexican oil industry.

Herramientas is a Mexican corporation, said to be capitalized for 30 million pesos. Bruno Pagliai is president. The company is building a manufacturing plant at Vera Cruz.

Under the agreement, M. E. Montrose, senior vice president and general manager of Hughes Tool said, cones and bearings will be manufactured by Hughes in Houston and supplied to Herramientas for installation on bit heads manufactured in Mexico. In this way, Montrose said, Mexican rig operators will be assured of bits made to the same exacting standards as those produced completely in the Houston plant. Full engineering and research facilities of Hughes will be available to Herramientas.

New Agent Appointed By Garrett For Israel

Garrett Oil Tools, Division of U.S. Industries, Inc., has announced the appointment of a new agent to handle sales of Garrett equipment in the Republic of Israel.



More than 1 million tons of mud have been weighed by Mud-O-Graf. This experience has led to the new, foam-proof, lost circulation-proof model.

A complete cycle of weighing is made every 45 seconds. The weighed sample is completely flushed out and passes over the shaker before the next fresh sample is taken.

The recorder can now be installed on the derrick floor without adverse effects from rig vibration on either its remarkable accuracy or its general operation.

Twenty years of experience in the mud weighing business has proved that there is no substitute for a completely accurate, continuous chart record of mud weight *placed in front of the driller.* Check these features:

- A weighing unit that will handle lost circulation material or foamy mud.
- The sample is taken every 45 seconds directly from the mud stream and is not dependent on pumping to a remote location.
- Each sample is completely flushed.
- The weighing unit is smaller and easier to maintain.
- Continuous recording on a circular chart, where a full twenty-four hours is visible to the driller.
- Recording is easily readable and accurate to 1/2 of 1/10 pound per gallon.

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For more data on advertised products, use Readers' Service Cards, last page.

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INDUSTRY RECOGNIZES KING GA SWIVELS BY THESE FAMOUS FEATURES:

- ALLOY STEELS assure strength with minimum weight.
- PACKING is V-type, often called chevron type.
- WASHPIPES are seamless alloy tubes, case-hardened and ground.
- GREASE LUBRICATION for the packing.
- MULTIPLE BALL BEARING UNITS provide ample capacity.
- OIL BATH LUBRICATION for the bearings.
- Choice of BAIL OR ELEVATOR SHANK.

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Suppliers' notes

Raphael Ben Yosef of Tel Aviv, Israel, will represent the firm in the sales of all Garrett equipment, including gas lift equipment, sleeve equipment, relief valves, safomatic valves, lease control systems, motor valves and drilling equipment.

San Diego Supply Company Opens New Sales-Warehouse

The San Diego Equipment and Supply Company has completed construction of a new warehouse and sales office on Mission Gorge Road in San Diego, Calif.

Specializing in construction, drilling and rock excavation equipment, the newly formed firm represents the Gardner-Denver Company, Bay City Shovel Company and Rock Bit Division of the Timken Roller Bearing Company.

J. W. Gallagher

The complete line of the latest equipment and accessories and the comprehensive parts and service departments will be maintained to provide 24-hour assistance on customer emergency calls. Also, field technical assistance will be made available as an additional customer service.

J. W. (Bill) Gallagher is the general manager of the new warehouse and office facilities.

Delta Tank Opens 24-City Oil Field Sales Offices

Delta Tank Manufacturing Company has confirmed establishment of a 24-city network of oil field equipment sales offices and supply houses in nine petroleum and gas-producing states.

The network will provide direct manufacturer-to-customer sales and service for a full line of oil field equipment, including Delta's "Dryex" Unit which recovers substantial quantities of raw gasoline, butane and propane previously lost in natural gas streams.

Office locations include Tulsa, Denver, Rock Springs and Casper, Wyo., Williston, S. D., Kimball, Neb., Hobbs and Farmington, N. M., Houston, Snyder, San Antonio, Dallas, Midland-Odessa, Corpus Christi, Pampa and Wichita Falls, Texas, New Orleans, Houma, Morgan City, Westwego, Shreveport and Lafayette, La., and Laurel and McComb, Miss.

Howard Supply Appointed Representative for Rolo

Howard Supply Company has been appointed representative for Rolo Manufacturing Company products in the State of California.

Howard Supply, headquartered in Los Angeles, has stores in Bakersfield, Taft, Santa Maria, Ventura and Long Beach, Calif.

Phoenix-Rheinrohr Operating Europe's Biggest Press

Europe's biggest bending press was taken into operation at the Thyssen Works at Muehlheim-Ruhr of Phoenix-Rheinrohr A. G., Duesseldorf, West Germany, one of Europe's largest steel and pipe manufacturers.

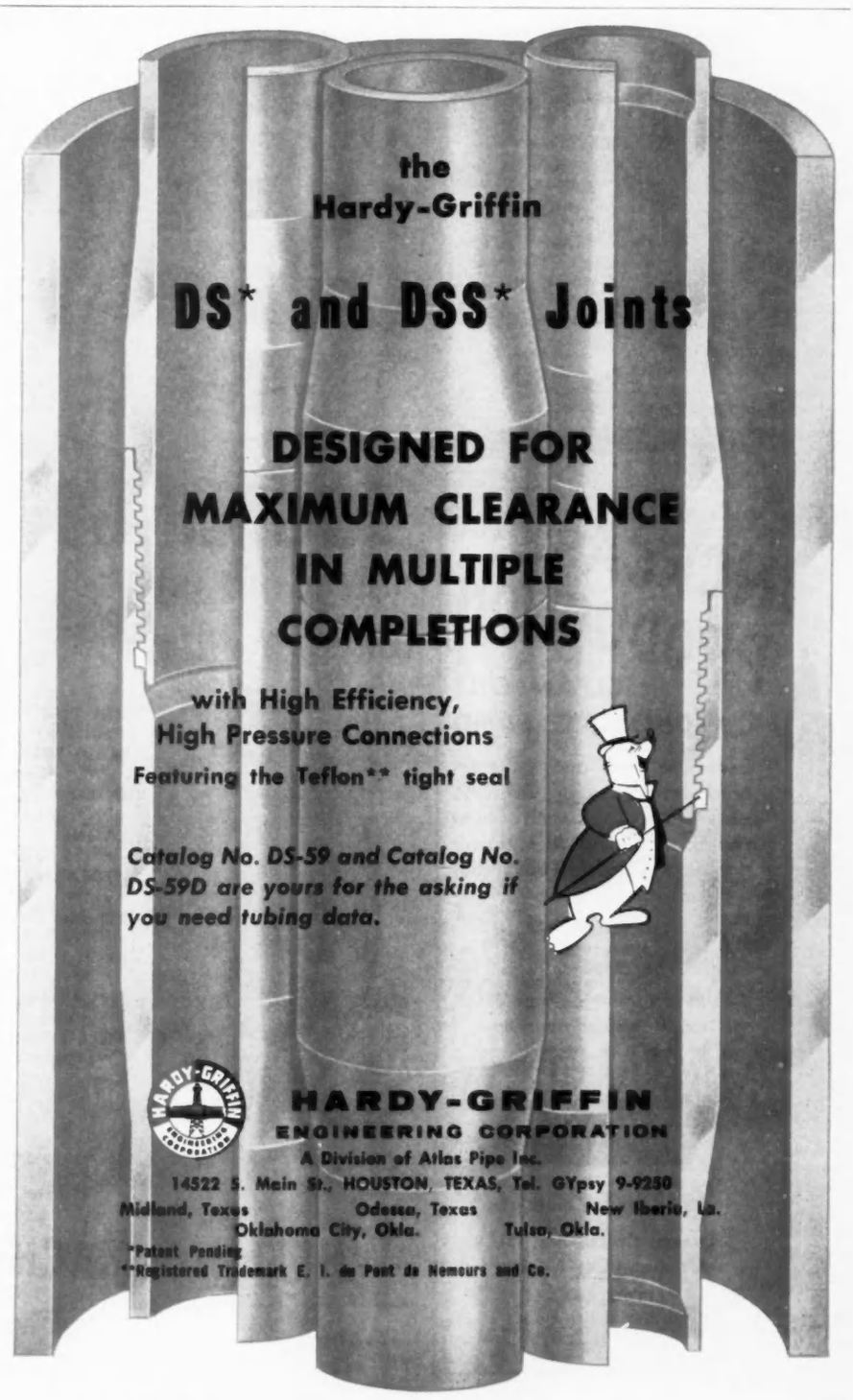
The 7,200-ton press is able to form heavy plates up to a thickness of 10 inches. The length of the cylindrical or conical half shells, which can be formed on this press, depending on the weight of the plate or bending radius and thickness respectively, is 40 feet maximum. The press can also be used for other operations after installing the respective tools, as for instance for the manufacture of segments for large spherical vessels and bottoms.

Fluid Brake Company New Houston Firm

The Fluid Brake Company, organized for the exclusive manufacture of fluid type auxiliary brakes, has been formed in Houston with offices on Cullen Boulevard.

Built for rotary drawworks and other types of heavy hoisting equipment, production is underway with some units already in the field.

Two sizes of the brakes, a series 420 and series 520, are being manufactured by the firm, according to Joe A. Lyne, president.



For more data on advertised products, use Readers' Service Cards, last page.

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Liquid Wrench works *fast*... yet is absolutely safe for all metals and alloys.

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SQUEAKS

From the Bull Wheel

When It's Your Time

Visitor (to Arizona native): "Say, what's the death rate around here?"

Native: "Same as anywhere else, bub. One to a person."

Definition of Americans

People who wish we would go back to letting Atlas support the world.

Surprise . . . Surprise!

The girl greeted her boy friend with, "Notice anything different about me?"

"Nope."

"Guess."

"New shoes?"

"No, something else."

"I give up."

"I'm wearing a gas mask."

Taking A Giant Step

Joe: "Can I have a cigarette?"

Moe: "I thought you'd quit smoking."

Joe: "I'm still in the first phase. I've quit buying."

This Time I'll Blow

A woman waiting at the door ready to go to the store had her arms full of coats and four little children at her side. Her husband, coming down the stairs, asked why she was standing there. She replied, handing him the coats, "This time you put the children's coats on and I'll go honk the horn."

Who Outranks Who?

The major looked up from his desk at the first-class private and snapped, "Now really, I ask you, in civilian life would you come to me with a puny complaint like this?"

"No, sir," was the reply, "I'd send for you."

Hard Work and Study

The big attraction at the carnival was a bear that played "The Star Spangled Banner" on the piano. Later a fluttery little lady approached the trainer.

"Goodness," she remarked, "What a remarkable act! How on earth did that bear ever learn to play the piano?"

"How does anybody learn?" snapped the trainer. "He took lessons!"

Gambler's Luck

Did you hear about the fellow who hit it good at Las Vegas? He went up there in an $8,000 Cadillac and came back in a $45,000 Greyhound.

INCREASE PRODUCTION

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Excessive sand and sediment holds back your oil. For fast, easy clean out with fewer round trips and less down-time, use world famous Miller Sand Pumps.

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WHEELING MACHINE PRODUCTS CO.

Wheeling, West Virginia

West Coast Factory: Woodlake, California

Nosey Relations

After a rather wild date with a charming young lady, the fellow worriedly asked, "Do you tell your mother everything you do?"

She responded. "Certainly not. Mother doesn't give a darn. It's my husband who is so inquisitive."

One in a Million

Professor: "Jones, can you tell me who built the Sphinx?"

Student: "I-I-I did know, sir, but I've forgotten."

Professor: "Great guns, what a calamity! The only man living who knows, and he has forgotten!"

Amen

He who talketh by the yard but thinketh by the inch deserveth to be kicketh by the foot.

Defend Thy Self

At the end of the fourth round, the heavyweight staggered back to his corner in a dazed and battered condition.

His manager approached him and whispered in his ear: "Say, slugger, I've got a swell idea. Next time he hits you, hit him back."

Calling All Cars

Police captain: "So you let him escape, huh? Didn't you obey my orders to guard all exits?"

Rookie cop: "Yes, sir, we guarded every exit. He must have slipped through one of the entrances."

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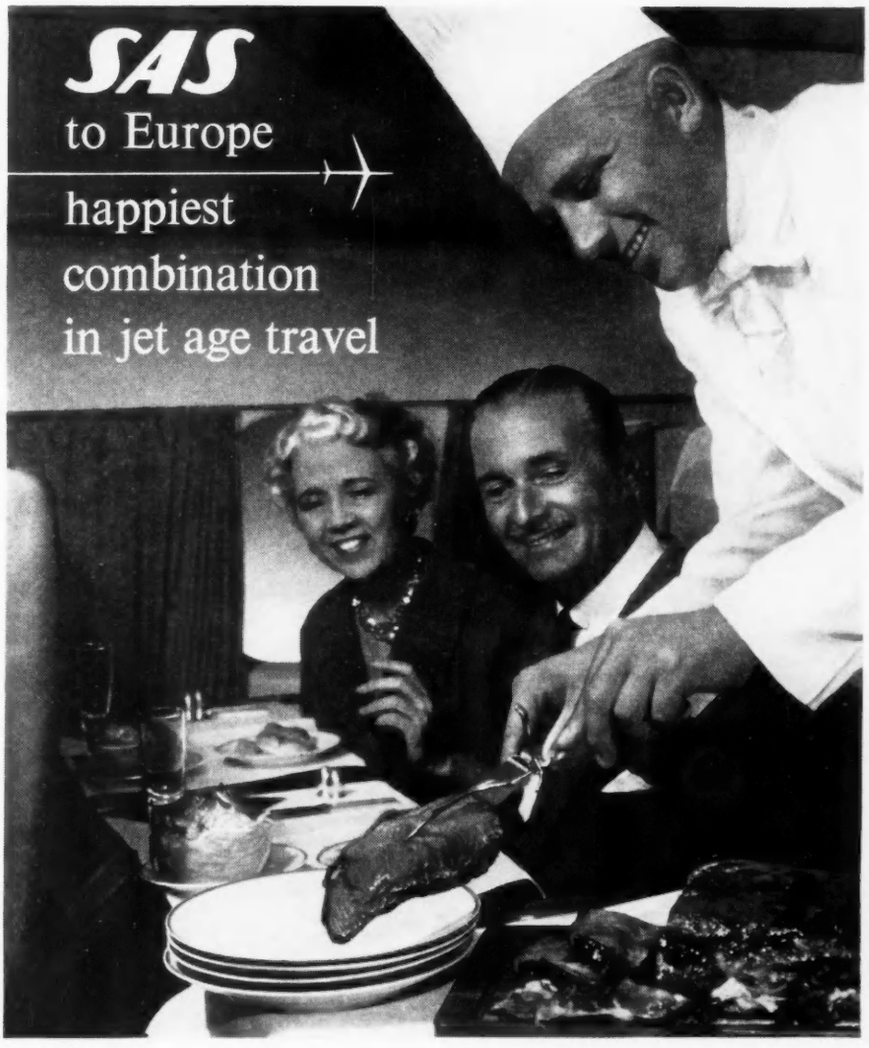

for him on business,
for both on vacation

Starting this spring, you speed to Europe, transatlantic or transpolar, with magnificent hospitality on the *SAS* DC-8 Jet Express. Then you whisk through Europe and the Middle East on the *SAS* Caravelle, world's quietest pure jet. And for a gala vacation, you pick from 100 sun-and-fun holidays in the stunning *SAS* brochure, "Treasure Chest of World Travel". . . free. Ah, here is the happiest combination in the jet age! *At* your *SAS* agent.

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NEW books, maps and movies

ANALYSIS CHARTS FOR THE DETERMINATION OF TRUE RESISTIVITY FROM ELECTRIC LOGS, Hubert Guyod and John A. Pranglin, P. O. Box 282, Bellaire, Texas, $22.50.

This book, for the first time, presents a method, and gives the necessary charts for determining simply and rapidly resistivities from an electric log comprised of the 16-inch and 64-inch Normals and the 18-feet 8-inch Lateral. The book contains over 250 charts that permit determining R_t and, in many cases, R_i and D_i for single beds from 2 to 50 feet thick and for comprehensive ranges of resistivities (R_t, R_i, R_s and R_m), holes sizes and invasion diameters. Instructions are given for the application of the data to certain non-uniform formations. A discussion of the resolving power of resistivity curves and of the effects of inaccuracies in the various pertinent factors (R_s, R_m, R, e and d) is offered.

BULLETIN 62, WELL LOGS IN TENNESSEE, State of Tennessee Department of Conservation and Commerce, Division of Geology, Nashville, Tenn., H. C. Milhous, $4.

This report consists of 606 pages. Data are mostly in the form of drillers' logs and sample descriptions, pertaining to 560 holes drilled in 68 Tennessee counties. The logs have been grouped by counties and the counties are arranged in alphabetical order. Included is an index map of the state which shows the Carter coordinate grid system.

RESISTIVITY DETERMINATION FROM ELECTRIC LOGS, Hubert Guyod, P. O. Box 282, Bellaire, Texas, $20.

This book was prepared in 1957 as a field manual for six major oil companies which have not released it for sale to the public. This manual gives the background necessary for the practical use of resistivity curves, and fundamental data for determining the resistivity of single beds and of multiple layer formations. At the time this book was prepared there was not enough data at hand on invaded beds, so that only a limited number of analysis charts are included for such beds. Typical logs are given for single beds (invaded, and non-invaded), multiple beds and sandwich-type formations. The Analysis Charts book mentioned in paragraph A supplements this field manual and these two books supply all the analysis data available at the present for the determination of resistivities from an electric log.

ELECTRIC ANALOGUE FOR RESISTIVITY LOGGING, Hubert Guyod, P. O. Box 282, Bellaire, Texas, $50.

This book was prepared in 1958 for six major oil companies as a report summarizing and analyzing some of the work done with our analogue computer. These companies have now released it for sale to the public. This report comprises two parts. The first part describes at length the analogue and its operation. The second is a thorough investigation of the response of Normal and Lateral resistivity curves on single and multiple beds. It discusses the apparent resistivities, shapes of curves, methods of analysis and other topics for Normal spacings from 0.75d to 15d and for Lateral spacings from 4d to 36d.

LIMESTONE AND DOLOMITE IN THE NORTHERN GABILAN RANGE, CALIFORNIA, Department of Natural Resources, Ferry Building, San Francisco, Oliver E. Bowen, Jr., and Cliffton H. Gray, Jr., California Division of Mines, 50 cents.

This paper describes in some detail the geology of eight square miles of terrain in the vicinity of Fremont Peak. Also, it includes a discussion of the general geologic features of the northern Gabilan Range, together with a generalized small-scale geologic map.

Work on the individual deposits extended from 1954 to late 1957. The data presented are complete to Jan. 1, 1958.

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■ Army surplus applicable drilling and producing. Star 71 repairs 50% off. V-belts in sets B-112-$2.00 each, B-173-$2.50 each, B-210 $3.00, postpaid. All material Army inspected, processed, unused. Write J. Brooke Reed, Fredericktown, Ohio.

CABLE TOOL EQUIPMENT

1—Walker-Neer Spudder—Model S-43. Working capacity depth—3500'. Sand Line, 3,500'; drilling line, 3,750'. 5 and 6 inch tools complete.
1—Walker-Neer Spudder—Model C-34. Working depth capacity—7500'. Sand line, 6,200', drilling line, 8,000'. 5 inch tools complete.
Both rigs dual mounted.
1—GMC 2-ton truck.
1—International 6x6, 3-ton truck.
Both trucks equipped with oil field beds and fifth wheels for moving rigs; dual trailer floats and winches; gin poles.
1—1959 V-8 Chevrolet ¼-ton pickup.
2—Dog houses.
3—Light plants.
Other miscellaneous accessories.

E. E. REED

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SITUATIONS WANTED

■ Petroleum Geologist, married, age 28, B.S. degree, with four years experience in South America in operation and exploration phases of geology plus training in petroleum engineering, desires position in the U.S. preferably in the Permian Basin. Box 212-W, WORLD OIL, Houston, Texas.